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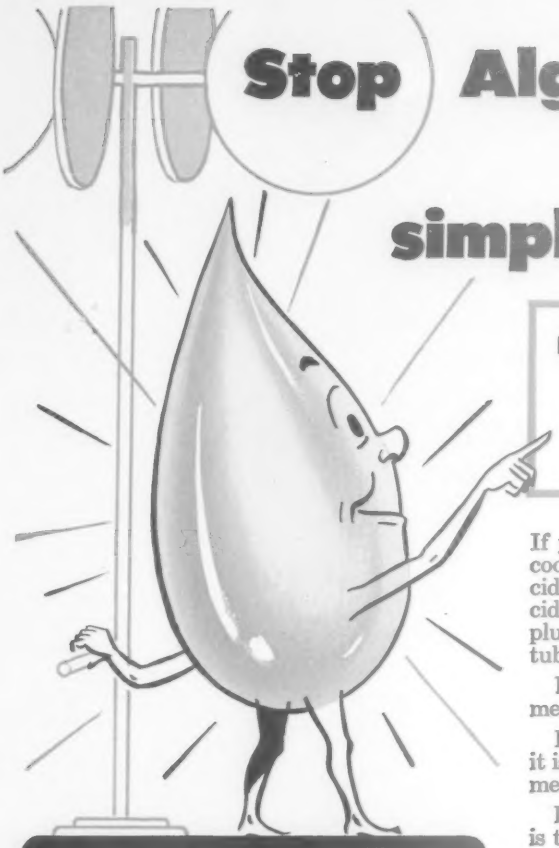
1ST QUARTER 1956

Electrical REVIEW

INSTALLING WORLD'S LARGEST PUMP-TURBINE...PAGE 10



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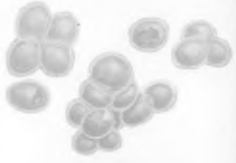

Protococcus

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Electrical REVIEW

THE COVER

DESIGNED FOR DOUBLE DUTY, the impeller-runner for the world's largest pump-turbine at TVA's Hiwassee Dam was assembled on the site and is shown near completion. When installed, it will help level the power system load curve in two ways: by using 102,000 hp of off-peak power to pump water at a rate up to three times the requirements of New York City; by reusing the pumped water to add 59,500 kw of rated capacity in meeting system peaks.

Cover color photo
by R. S. Dominick
Allis-Chalmers
Service Section

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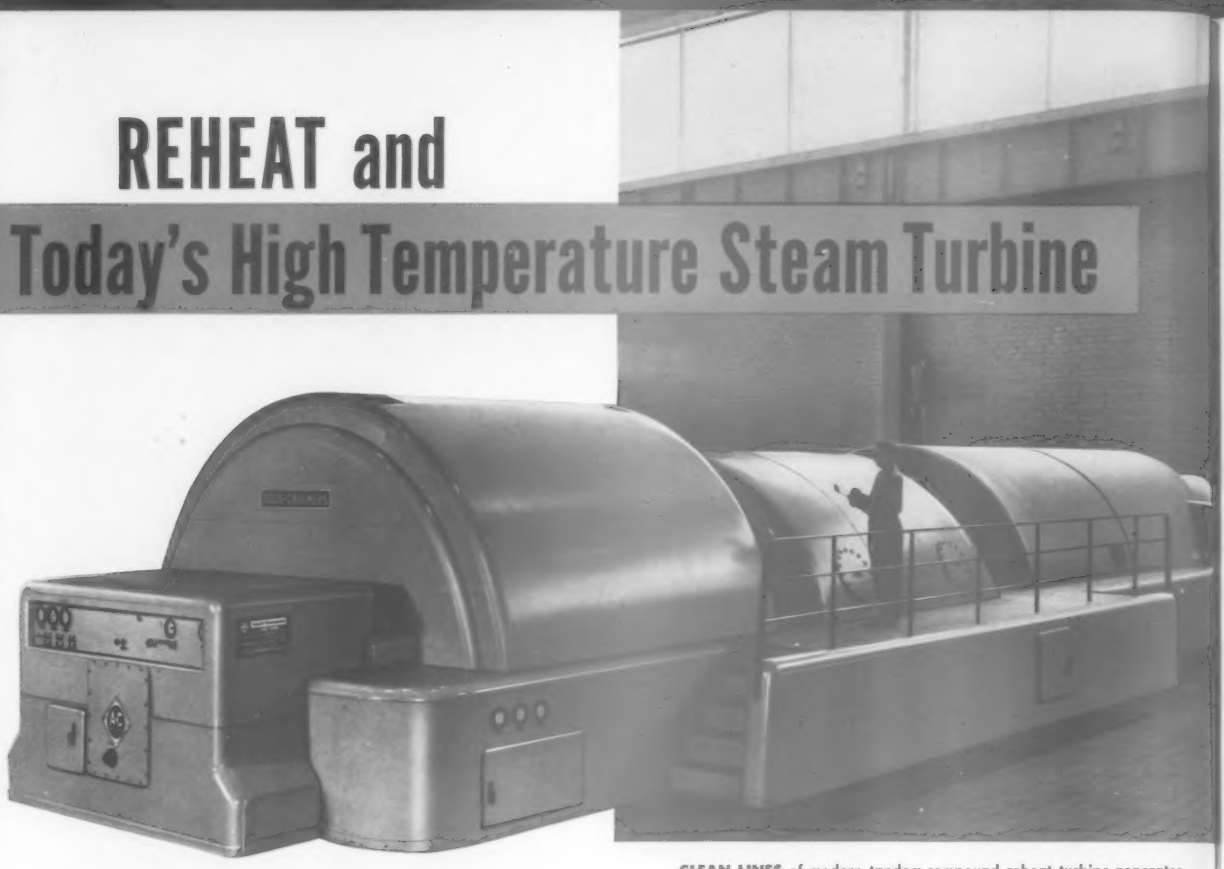
REHEAT and Today's High Temperature Steam Turbine



CLEAN LINES of modern tandem-compound reheat turbine-generator units are dramatized by this 100-mw installation. **(FIGURE 1)**

by C. D. WILSON
Chief Design Engineer
Steam Turbine Department
Allis-Chalmers Mfg. Co.

Universal acceptance of reheat for large turbines in the late forties encouraged development of the many types and ratings of large steam turbines being built today.

DURING the more than twenty-five years since the first reheat turbine went into service, turbines and generators have grown larger in capability and smaller in size per kilowatt-hour produced. Steam temperatures and pressures have gone up, while overall heat rates have come down. Protective controls have been added as the operation of reheat machines has been simplified.

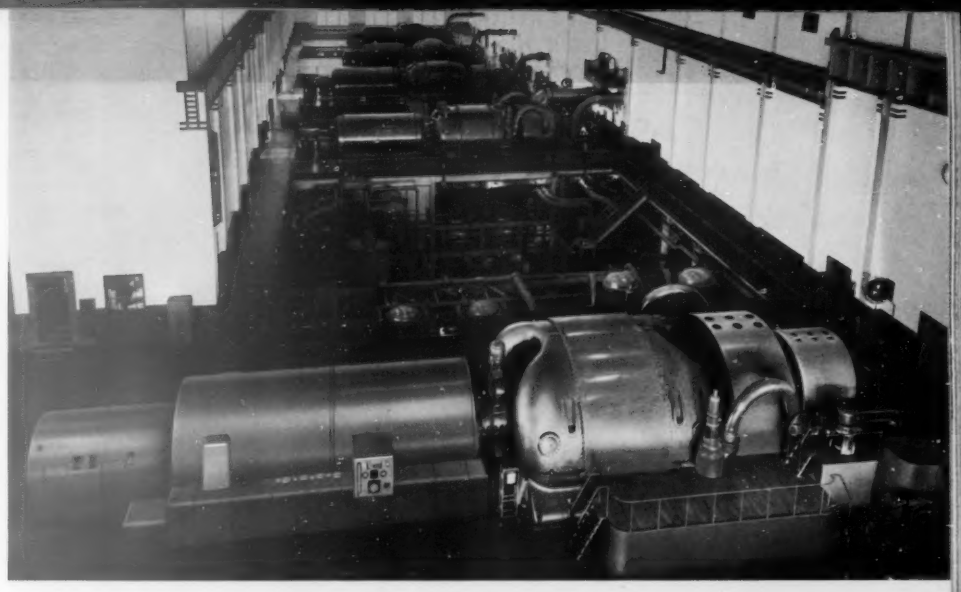
Even the reasons for using the reheat cycle have changed. In recent years, reheat has been used primarily as a means of increasing turbine efficiency. When reheat was first used, however, metallurgy limited maximum steam temperatures to 750 F, and one of the major reasons for using reheat was to reduce moisture and consequent erosion in the low pressure turbine and exhaust section.[1] Reheat turbines typical of that period are shown in Figure 2.

The turbine in the foreground was installed in 1931. Designed for 650 psi, 750 F steam with 750 F reheat, this unit is particularly interesting because it shows the original turbine with a recently installed modern hydrogen-cooled generator. With the new generator, this unit has now been rerated from 115,000 to 121,000-kw capability. The adjoining unit, installed in 1930, is rated 65,000 kw with 650 psig, 750 F inlet steam and 750 F reheat. Like all machines of their day, these turbines are physically large 1800-rpm units with exposed valves, piping and mechanisms.

Both machines have separately fired reheaters. Reheat control consists of one intercepting valve in the reheat return line and two steam-unloading valves discharging to the condenser through flanged openings in the exhaust hood.

Few reheat installations, 1935-49

During the thirties, advances in metallurgy were reflected in the use of carbon vanadium and carbon molybdenum steel for forgings, castings and pipe. These new materials permitted higher steam temperatures which, in turn, reduced the moisture problem in the low pressure turbines being installed at that time. Consequently, very few turbines designed for the reheat cycle were installed in public utility stations during the period between 1935 and 1949.



25 YEARS OF REHEAT at Waukegan station of Commonwealth Edison Company's Public Service Company Division — represented by Units 4 and 5 in foreground, which are rated 65,000 and 121,000 kw respectively. **(FIGURE 2)**

One of the few exceptions was the Port Washington station of the Wisconsin Electric Power Company, where all of the machines employed the reheat cycle. Installed in 1935, the first unit in this station, an 80,000-kw, 1800-rpm tandem-compound machine, was designed for the now almost universal single-boiler, single-turbine arrangement and operated with 1230 psi, 850 F steam, 850 F reheat. During succeeding years, four more 80,000-kw reheat units were added, the last in 1950. Operation of the Port Washington station was so successful that it held the world's record for best station heat rate for the thirteen years from 1936 to 1948, and its record has been exceeded only by stations having reheat units of larger capability or operating with more advanced steam conditions. This station, as it appears today, is shown in Figure 3.

Resurgence of reheat

Starting about 1948, rising fuel costs plus the excellent performance record of existing reheat machines revived interest in the reheat cycle for application to large central-station units. This was emphasized by the Symposium on Reheat, given at the 1948 ASME annual meeting.[2] Additional impetus was stimulated by increasing system loads and the introduction of chromium molybdenum steels, which made it possible to use ferritic materials for steam temperatures up to 1050 F. Temperatures of 1000 F became commonplace on large reheat machines, and steam pressures of 1450 psig, 1800 psig and higher were used with 1000 F and higher temperatures. In 1951 the first supercharged hydrogen-cooled generator was placed in service,[3] setting the stage for the large capability reheat units that were being designed.

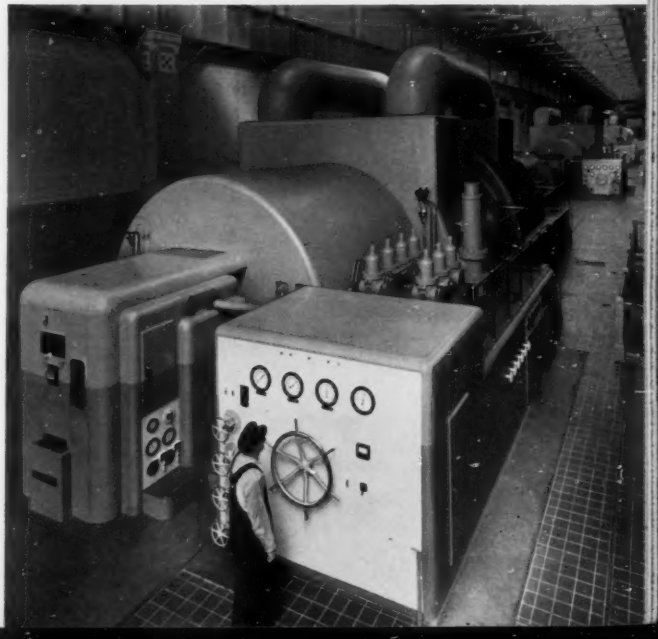
Two general types of reheat machines evolved. They can be broadly classed as (1) large tandem-compound units driving single 3600-rpm generators, and (2) cross-compound machines with 3600-rpm high pressure, high temperature turbines and an 1800-rpm low pressure turbine.

Evolution of close-coupled design

An interesting development that evolved in 1950 was the close-coupled arrangement of the cross-compound turbine.[4] This arrangement permitted substantial reduction in the size of the turbine room required for a large unit. The first close-coupled cross-compound machine went into service in 1953. Located in the Oak Creek power plant of the Wisconsin Electric Power Company, it is a 120-mw unit designed for 1575 psig, 1000 F inlet steam, 1000 F reheat and ½-inch Hg absolute exhaust pressure. Two additional units of the same rating but higher initial steam pressures, 1800 and 2000 psig, respectively, have since been installed, and a fourth unit, also for 2000 psig, is under construction. The station, as it looks today with three units installed, is shown in Figure 4.

Crossunder pipes are very short, and either balanced or hinged expansion joints are used to take care of thermal

WORLD'S RECORD for best station heat rate was held from 1936 to 1948 by the station equipped with these five 80,000-kw, 1800-rpm reheat tandem-compound turbines. **(FIGURE 3)**



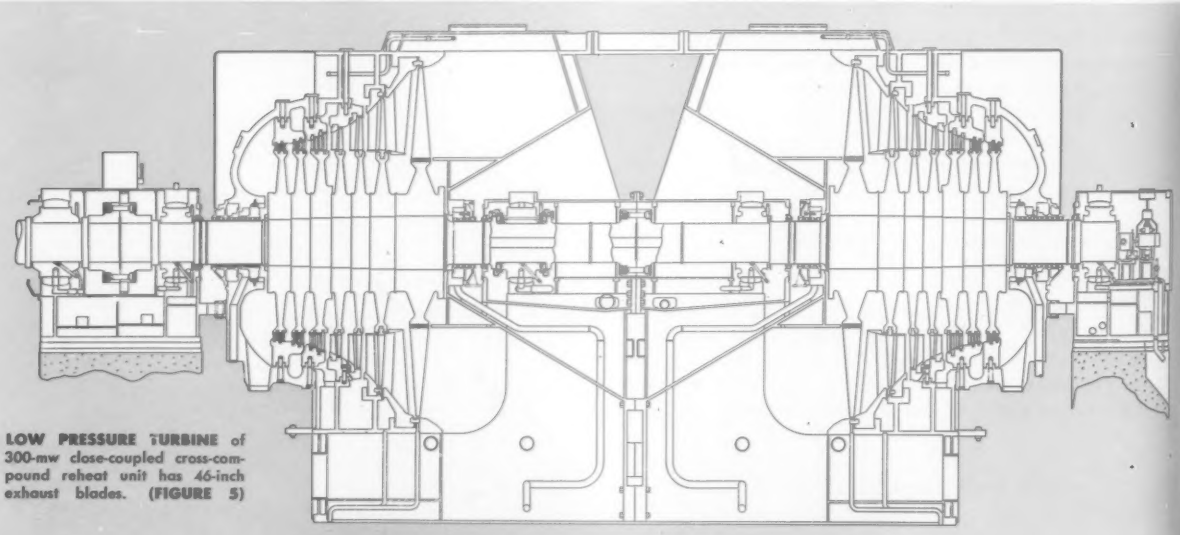
FIRST CLOSE-COUPLED cross-compound reheat steam turbine-generator units in the world are these three, rated at 120 mw each, at the Oak Creek station of Wisconsin Electric Power Company. **(FIGURE 4)**

expansion and steam pressure thrust forces. The resulting unit, with two generators and divided turbine, is much shorter than the corresponding tandem 3600-rpm machine. In addition, this design can be used for larger capabilities because of the inherently larger exhaust area of the 1800-rpm low pressure turbine. Because of this characteristic, close-coupled cross-compound machines are ideally suited for stations located where cold water is available for the condenser, and for all locations where unit capability of 250 mw or larger is desired. Compact size makes this design especially attractive for installation in older stations when a unit of larger capability is needed to replace a smaller obsolete machine.

Two recent applications of the close-coupled cross-compound arrangement are the 300-mw turbine generator for the Detroit Edison River Rouge station and the 300-mw unit for Commonwealth Edison Company's Fisk station. The Detroit machine is designed for 2400 psig, 1050 F inlet steam, 1000 F reheat and 1-inch Hg absolute exhaust pressure. The Commonwealth Edison unit is the same except the steam pressure at the inlet is 2000 psig.

Both of these turbines utilize the cross-compound design possibilities to the utmost and feature two-flow exhausts. Exhaust blades used in the 1800-rpm low pressure turbines are 46 inches long. A cross section of the 1800-rpm elements, Figure 5, shows two separate LP turbines. Arranged back to back, they exhaust to a common condenser, with each shaft supported on two bearings. Low pressure spindle blades are mounted on separate alloy steel blade rings which, in turn, are shrunk on a small diameter carbon steel shaft.

The high speed element, shown in Figure 6, consists of a double-casing high pressure turbine which exhausts to the reheat boiler, and a double-flow, double-casing intermediate pressure turbine which admits high temperature reheat steam at the center. From this center inlet,



LOW PRESSURE TURBINE of 300-mw close-coupled cross-compound reheat unit has 46-inch exhaust blades. **(FIGURE 5)**

steam flows in opposite directions within the IP turbine to exhaust connections at the extremities of the turbine. Here, the steam continues through two short crossunder pipes to the two low pressure turbines. This design permits high speed, high temperature turbines of relatively small size. Shaft forging diameters are 39¼ inches on the IP turbine and 31½ inches on the high pressure turbine. Opposed flow within the IP turbine balances steam thrust and at the same time reduces blade size and blade stress in a machine handling large volumetric steam flow.

The crossunder pipes on this machine, located above the foundation and below the operating platform between the two turbines, are short and direct. The general appearance of this 300-mw unit is indicated by the scale model pictured in Figure 7.

The close-coupled arrangement is made possible by mounting both high speed and low speed elements close together on a common foundation, as shown in Figure 8.

Tandem design to 250 mw

Paralleling development of the close-coupled cross-compound reheat machines, the 3600-rpm tandem turbine arrangement has progressed rapidly in recent years. With the development of the 26-inch exhaust blade and the "supercharged" hydrogen-cooled generator, it is now possible to build single-generator, tandem-compound 3600-rpm machines with capabilities up to 250 mw. Smaller machines of this type now in service are compiling excellent operating records. Stable under all operating conditions, they are efficient performers that are simple to operate.

One of two 75-mw tandem turbines, installed in the Rock River station of the Wisconsin Power and Light Company, is shown in Figure 9. These are the prototypes for large 3600-rpm tandem reheat machines and operate with 1450 psig, 1000 F inlet steam, 1000 F reheat and 1-inch Hg absolute exhaust pressure. Clean-cut appearance is achieved by locating valves and steam chest in an accessible position below the floor line alongside the unit, and by using side crossunders which are permanently connected to the lower half of the turbine below the side platforms. These features are typical of the arrangement used on all the large tandem 3600-rpm reheat machines.

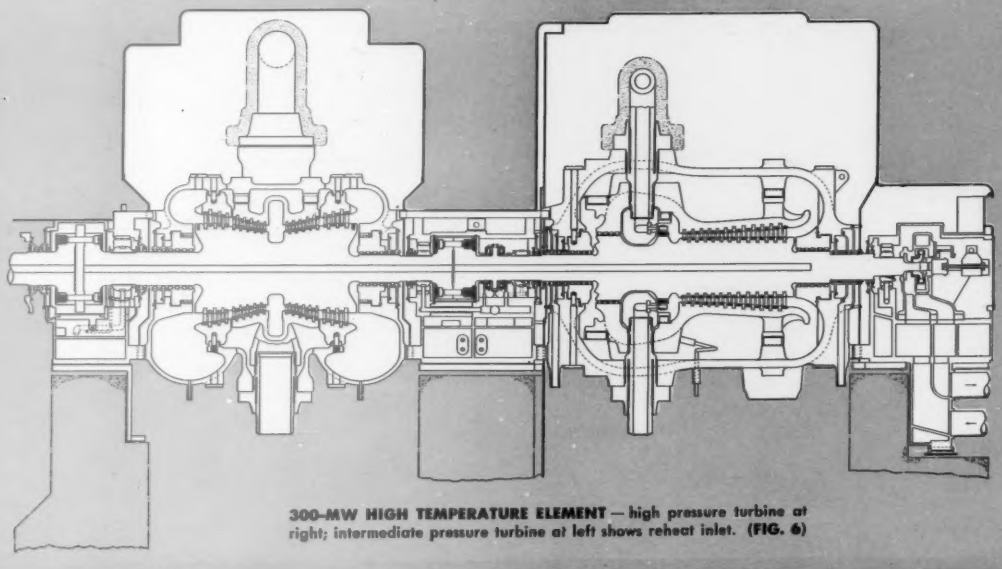
A larger installation, the 100-mw, 3600-rpm tandem reheat machine installed in the power station of a large midwest utility, is shown in color on pages 16 and 17. This machine is designed for 1450 psig, 1000 F inlet steam, 1000 F reheat and uses a two-flow exhaust having 23-inch long exhaust blades for the 1½-inch Hg absolute exhaust pressure.

Two 150-mw, 3600-rpm tandem reheat machines, now being built for the New Albany station of the Public Service Company of Indiana, Inc., will look like the model shown in Figure 10. These units will operate with 1800 psig, 1000 F inlet steam, 1000 F reheat and 1½-inch Hg absolute exhaust pressure. A cross section through this turbine, Figure 11, shows the double-casing high pressure turbine and side crossunders connecting to the double-flow fabricated steel low pressure turbine which has 26-inch long exhaust blades. Larger capability machines of this type can be built by using more than two flows of low pressure blading.

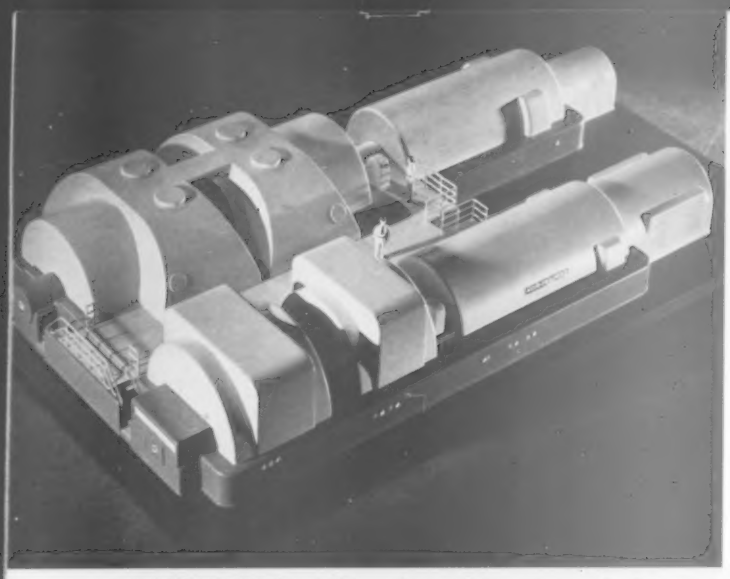
Tandem 3600-rpm reheat designs are suitable for machines up to about 250 mw, depending upon available exhaust pressures. The location of all valves and mechanisms below the floor line on machines of this type, plus the non-sliding design used on all the bearing pedestals, permits easy adaptation of these 3600-rpm tandem machines for complete outdoor installation.

Evolution of reheat control

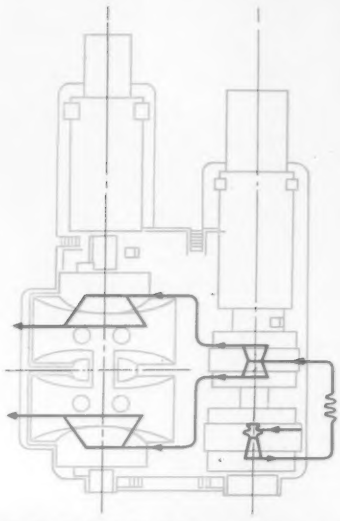
Operating experience with reheat turbines during the past 25 years has guided the development of the modern controls used on present-day machines. Standard controls now furnished on these machines include two reheat intercepting valves which are in series with back-up trip stop valves. The intercepting valves begin closing by action of the speed governor whenever the turbine speed becomes higher than 1½ percent above normal. They operate in a manner similar to the governor-controlled inlet valves. Back-up trip stop valves are closed by the turbine trip system.



300-MW HIGH TEMPERATURE ELEMENT — high pressure turbine at right; intermediate pressure turbine at left shows reheat inlet. **(FIG. 6)**



DESIGNER'S MODEL of 300-mw close-coupled cross-compound reheat steam turbine-generator unit. Despite large rating, it will occupy minimum floor space. Generator for high speed element (right) is fully supercharged. **(FIGURE 7)**



300-MW UNIT STEAM FLOW — turbines after reheat inlet are inherently balanced by double-flow design of intermediate and low pressure turbines. **(FIGURE 8)**

Because modern machines are provided with two parallel reheat lines, it is possible to close one set of intercept and back-up stop valves completely, one at a time, while the turbine is carrying load. This full-stroke exercising of these important valves at regularly scheduled intervals assures the operator of their ability to function properly when needed.

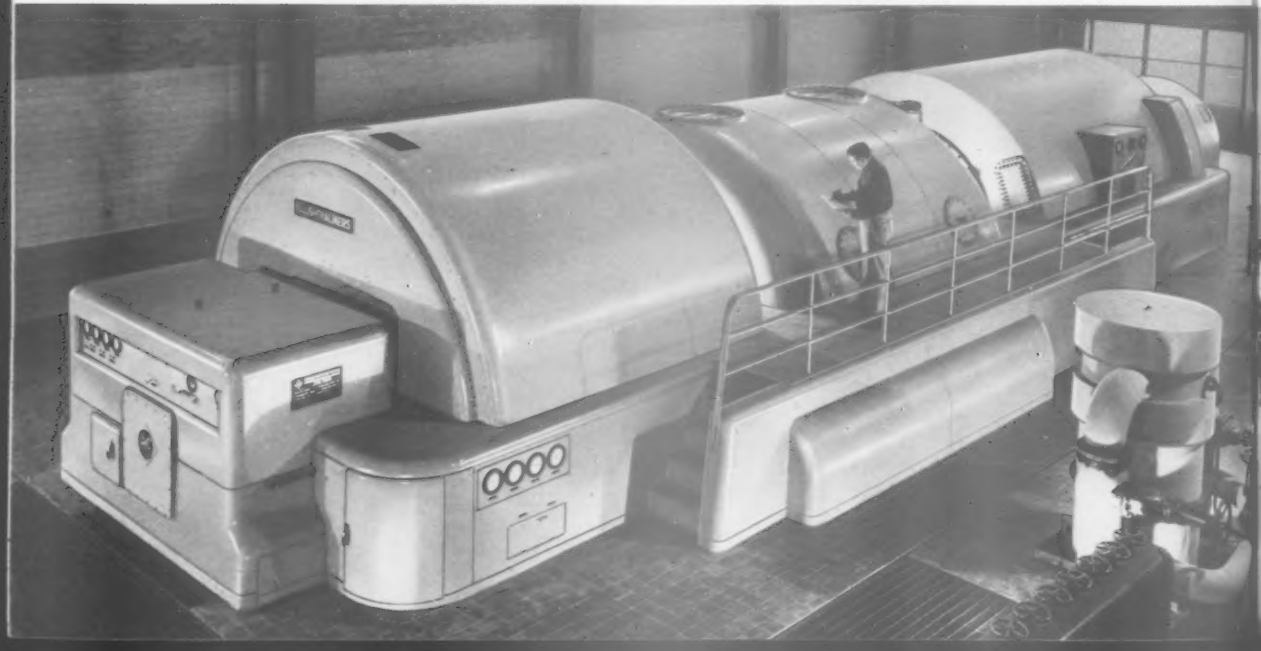
Automatic hydraulic interlocks insure that the back-up stop valve, which is an unbalanced valve, re-opens before the intercepting valve. The higher potential overspeed of 3600-rpm tandem reheat machines larger than 100 mw has required faster valve closing. This is accomplished by anticipator devices which start to close the intercept and governor-controlled inlet valves before the speed increases sufficiently to operate the normal governor devices.

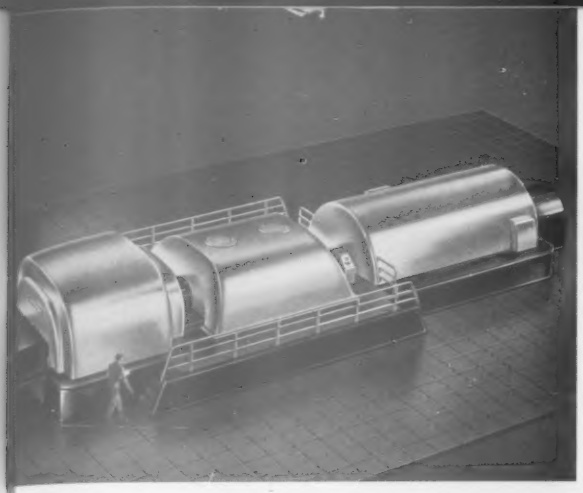
Modern reheat machines are designed to avoid speeds in excess of tripping speed even with load dump, and to hold the speed below 120 percent normal speed if any single control device fails. A more detailed discussion of controls used on reheat turbines can be found in technical papers published by the American Society of Mechanical Engineers.[5]

Improvements in heat rate

Turbine heat rate, expressed in Btu per kwhr produced, is used as a measure of turbine performance. The application of one stage of reheat results in an average gain of about 4½ to 5 percent over the performance of a similar non-reheat unit. Early reheat machines, operating with 600-psi pressure and temperature of 750 F, had turbine heat rates in the order of 9800 Btu per kwhr. Modern reheat machines, operating with steam pressures up to 2400 psig and temperatures up to 1050 F, have turbine heat rates ranging from 7300 to 8000 Btu per

NEW TREND in tandem reheat design was established by first of two 75-mw side crossunder units at Rock River station of Wisconsin Power and Light Company. **(FIG. 9)**





COMPACT 150-MW UNIT, illustrated by model, combines tandem side-crossunder reheat turbine and fully supercharged generator. **(FIGURE 10)**

kwhr, depending on the specific steam conditions used, the heat cycle, and the turbine capability. This 25-year improvement in turbine heat rate has resulted chiefly from (1) the increase in available energy resulting from the more advanced steam conditions now used, (2) from advances in turbine aerodynamics leading to higher internal efficiencies, and (3) from the increase in turbine capability which permits more efficient sizing of the steam path.

Future of reheat

How can further improvements in turbine performance be made? One way is to increase the available energy by going to still higher pressures and temperatures. Metallurgical advances plus refinements in design are permitting a further increase in steam temperatures to 1100 F and 1150 F. Design studies for cycles using these temperatures with supercritical pressures have shown that turbine heat rates of 6700 Btu per kwhr are in the offing. Either single or double reheat will be used, depending on the initial steam pressure and temperature selected. Designs are now on the drawing boards[6] for supercritical pressure turbines using inlet steam temperatures of 1150 F. Reheat is still very much in the picture on these new machines, and where double reheat is used the second stage of reheat will provide approximately 1½ percent gain in performance over the nominal 5 percent obtained with single reheat.

With reheat firmly established as a means of increasing the efficiency of high pressure, high temperature units, reheat is now being considered for nuclear power plants for an entirely different purpose—the same purpose for which it was originally used over 25 years ago. Steam pressures and temperatures obtained from the first nuclear reactors will be moderate. The problem of excessive moisture in the turbine exhaust will again require attention. Improved methods of moisture removal from the low pressure turbine will help, but reheat, either in the form of separately fired reheaters or steam heat exchangers—both of which are now receiving consideration—may play an important part in this newest development, the nuclear power plant of tomorrow.

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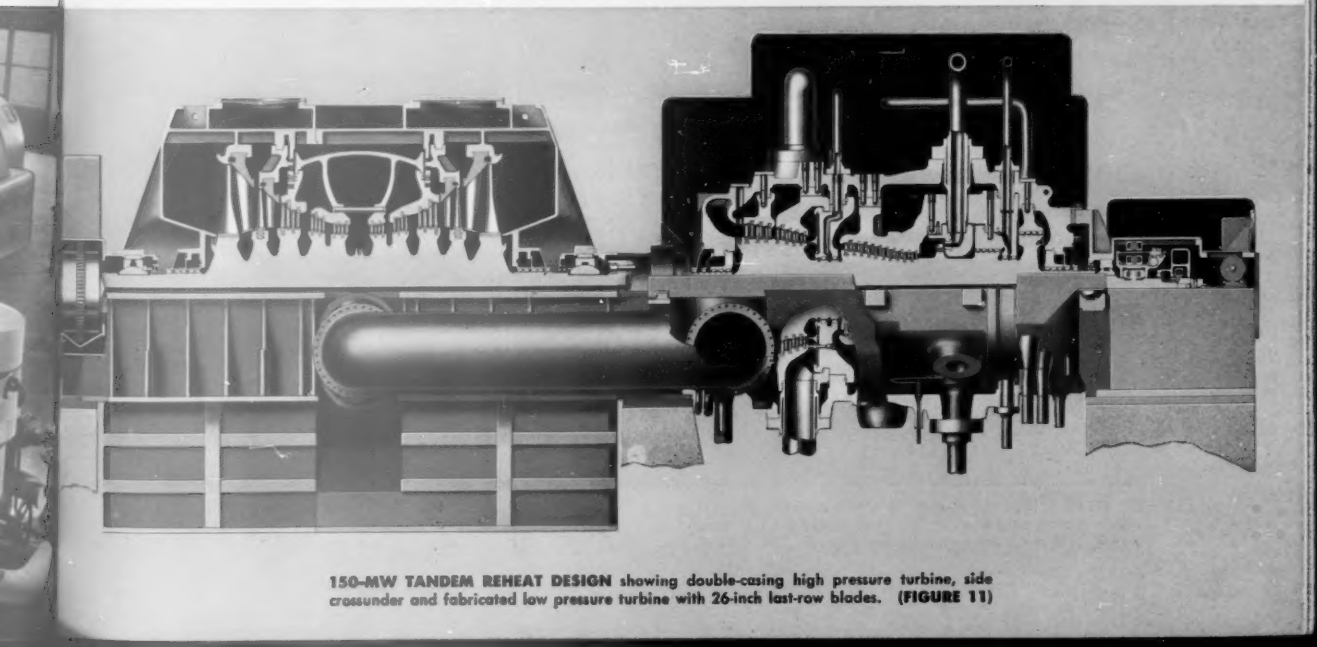


150-MW TANDEM REHEAT DESIGN showing double-casing high pressure turbine, side crossunder and fabricated low pressure turbine with 26-inch last-row blades. **(FIGURE 11)**

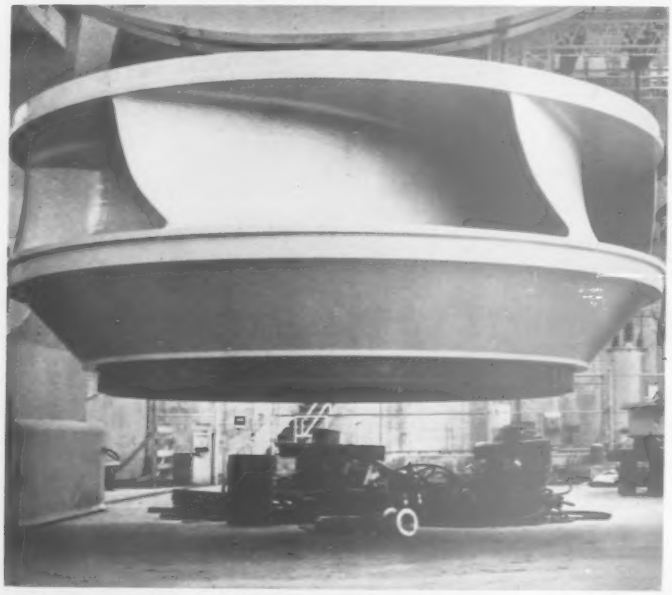
Installing World's Largest Pump-Turbine

ONE OF 20 wicket gates which will control flow of water from the welded joint scroll case into the runner-impeller is being lowered into place. **(FIGURE 3)**

by **R. M. LEWIS**
and
R. S. DOMINICK
Service Section
Allis-Chalmers Mfg. Co.

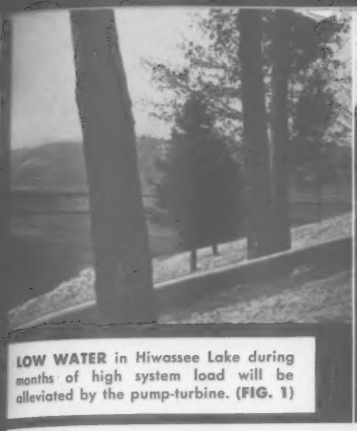
ERECTION of the world's largest reversible pump-turbine at Hiwassee Dam in southwestern North Carolina began when the inlet pipe connection to the original penstock was positioned for welding in November 1954, about 15 years after the first unit went into service at this 307-ft high concrete gravity dam.

When originally constructed, the dam was built with an open bay adjacent to the 57,600-kw initial turbine-generator. Although this bay was designed to accommodate a unit that would duplicate the first, increasing need for

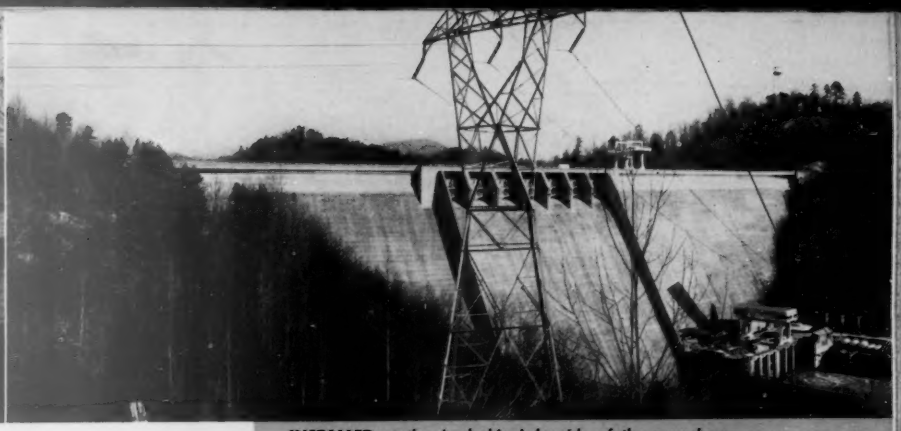


WHEN WEAR RINGS were fitted onto this 266-inch diameter three-piece runner, strip heaters were used to expand the rings, water spray to contract the runner for the shrink-fit. **(FIGURE 4)**

FROM THE 18-FOOT diameter penstock, water will fill the scroll case, surround the stay ring and wicket gates. **(FIGURE 5)**



LOW WATER in Hiwassee Lake during months of high system load will be alleviated by the pump-turbine. **(FIG. 1)**



INSTALLED at the Apalachia Lake side of the powerhouse (see arrow), the pump-turbine unit will lift 3900 cfs of water into Hiwassee Lake or generate 80,000 hp. **(FIGURE 2)**

system peaking capacity during the intervening years made it economically attractive for the Tennessee Valley Authority to install a reversible pump-turbine.*

Vital to any pump-turbine installation is a suction pool or downstream reservoir of sufficient size to permit a pumping cycle. At Hiwassee Dam, the suction pool is Apalachia Lake, with its 58,570 acre-feet of water. Formed by Apalachia Dam, nearly 10 miles downstream on the Hiwassee River, and backing up to Hiwassee Dam, this lake provides controlled storage for 8700 acre-feet of usable water.†

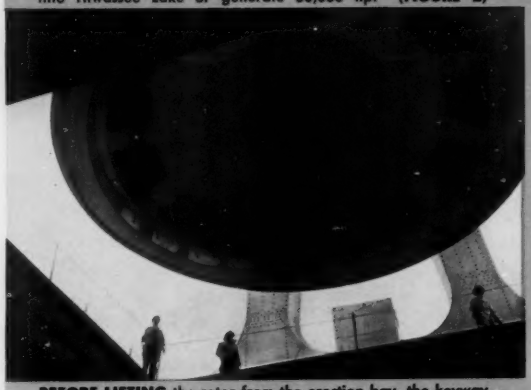
During periods of peak power demand, the pump-turbine will function as a conventional turbine-generator, adding 59,500 kw of rated capacity to the system. During hours of low power demand, especially throughout the season of minimum rainfall, surplus power from the TVA system will be fed into the generator/motor. As a motor-driven pump, rotating in the opposite direction, the unit is rated to pump 3900 cfs from Apalachia Lake back into Hiwassee Lake against a 250-ft head.

In this way, surplus electric power will be stored as additional water in Hiwassee Lake for reuse during the next peak-load period.

As is the case with almost all large, modern hydraulic installations, size restrictions were imposed by shipping limitations. Clearances along rail right-of-ways from Milwaukee to Turtletown, Tenn., required that the scroll case, the stay ring, and even the Francis-type runner of the pump-turbine be shipped in sections. At Turtletown, parts were transferred to low-bed tractor trailers and hauled the remaining twelve miles to the Hiwassee Dam powerhouse. Generator/motor parts were also shipped in sections: the stator in three sections, wound except for a few coils at each parting, and the fabricated rotor spider in three sections. Laminations were stacked and pole faces were attached to the rotor as a part of field assembly.

In 1955 on April 20th scroll case welding was finished and hydrostatic tests were made. Second-stage concreting was started in May, and 82 percent completed by July, when the cofferdam was removed and generator rotor stacking begun.

In February of 1956 erection of the pump-turbine and generator/motor was completed. Electrical and hydraulic tests on the world's largest motor and world's largest pump-turbine were then begun.



BEFORE LIFTING the rotor from the erection bay, the keyway through which the world's largest motor will drive the pump shaft was expanded 0.018 inch by heating. **(FIGURE 6)**

READY FOR INSTALLATION, the 330-inch diameter rotor will be lowered into the 331-inch diameter stator, the expanded keyway mated to the key. **(FIGURE 7)**

CRUSHING STICKS of ¼-inch plywood, held in the ½-inch air gap between the stator and rotor pole faces, assured proper centering of the rotor as it was lowered. **(FIGURE 8)**

* "Pump-Turbines . . . 1954 Progress Report," Frank E. Jaski, "Generator-Motor Units for Reversible Pump-Turbines," H. H. Roth, both in 4th Quarter, 1954 Allis-Chalmers *Electrical Review;* and "Pump-Turbine Addition at TVA Hiwassee Hydro Plant," L. R. Sellers and J. E. Kirkland, Jr., March 1956 *Electrical Engineering.*

† One acre-foot equals 43,560 cubic feet.

Distribution System VOLTAGE STUDY

by H. L. DELONEY
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and
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Proper proportioning of voltage drops from the last user back to the power source is an effective way of solving system voltage problems.

GREATER EMPHASIS on distribution system planning is the result of the rapid growth of power needed by individual users. Arriving at an economical system arrangement which will deliver satisfactory voltage to the user requires a systematic approach to the problem. A study of a typical system illustrates such an approach.

A distribution system combines primary feeders, primary laterals, distribution transformers, secondaries, and services, as shown in Figure 1. In this study a satisfactory user voltage is one which is no higher than 126 and no lower than 114, with a maximum variation to any one user of not more than 8 volts.

The power sources referred to are either generating stations or transmission connections to neighboring systems. As power flows from these sources to the load on distribution systems, there is voltage drop in the transmission system and in the substations that transform the power from transmission voltage to distribution voltage. These voltage drops are not considered further except to say that they are corrected by means of bus regulators or load tap-changing transformers at the distribution substations.

A few years ago a substantially greater voltage spread was generally considered satisfactory and evoked very little complaint. Today's widely increased use of electric power causes greater voltage drop, and the introduction of more sensitive appliances has created the band of 114-126 volts for "satisfactory service," within which limits complaints are few.

Voltage drop is divided

Table I shows how voltage drop can be divided among the components of a well-designed distribution system to maintain service voltage within satisfactory limits. Starting from the user's meter and working toward the source, the normal voltage drop in each of the component parts of the distribution system is plotted in the voltage profile of Figure 2.

SATISFACTORY VOLTAGES to the user will require various voltage-regulating methods to minimize the effect of load changes.

The service drop

The maximum voltage drop in the service seldom exceeds 1 volt at full load and can be considered to be a minimum of ½ volt. There are times when the customer takes no power (and the drop is zero), but the error introduced by the assumption of ½-volt minimum is inconsequential.

The secondary

Some customers are served directly from a transformer and are not affected by secondary voltage drop. Secondaries may be designed for approximate voltage drops of 2 percent, increasing to 3 percent with load growth. When voltage drop in the secondary reaches 3 percent, additional

Allowable Voltage Drop In the Components of the Distribution System (TABLE I)

	First Customer		Last Customer	
	Heavy Load	Light Load	Heavy Load	Light Load
Service	0.5	0.5	1.0	0.5
Secondary	0.0	0.0	3.5	1.0
Distribution Transformer	2.5	0.5	5.0	1.5
Primary Lateral	0.0	0.0	1.5	0.5
Primary Feeder	2.0	0.5	6.0	2.0

distribution transformers can be installed to reduce the drop to approximately 0.75 percent. Therefore, the permissible range of secondary voltage drop is from 0 to 3.6 volts on a 120-volt base.

Distribution transformer

The peak load on distribution transformers at the time of installation should be in the order of 80 to 100 percent of nameplate rating, and the loading with load growth should be allowed to reach about 150 to 160 percent of nameplate rating. For this range of loadings the voltage drop in distribution transformers varies from approximately 2½ volts to 5 volts at the time of full load.

From the practical standpoint the load taken by a group of users on a single distribution transformer is uncontrollable and the voltage drops in the service, secondary, and distribution transformer are unpredictable. That is, at any heavy load period the voltage drops through these three components of the distribution system will be minimum at some transformer locations near the source, and maximum at other transformer locations near the ends of the primary. For the minimum load condition, the drop is only 3 volts, while for maximum load, 9.6 volts. It appears that there is a variation of 6.6 volts about which nothing can be done; however, proper use of corrective means can substantially reduce that difference.

Point *A* of Figure 2 is the starting point of 114-volt minimum satisfactory voltage at the user farthest electrically from the source. This user has the maximum permissible voltage drops in each of the three components of the distribution system — service, secondary, and transformer — which are shown by the solid line from *A* to *B*.

Next, consider the user closest electrically to the source. The maximum satisfactory service he may be given is 126 volts, or point *C*. This user may be considered to have only ½-volt drop in his service, may be fed directly from a power transformer with no secondary voltage drop, and may be fed from a lightly loaded distribution transformer having only 2½-volt drop. This condition is shown by the solid line from *C* to *D*.

Primary

The primary feeder leaving the source normally has a conductor size of between No. 2 and No. 4/0 copper equivalent. Near the source this circuit may serve distribution transformers connected directly to the feeder or to short laterals. Some distance from the source the feeder may branch in several directions and each branch may be fairly long. Such branches are not called "laterals" but are parts of the main feeder and should be considered individually.

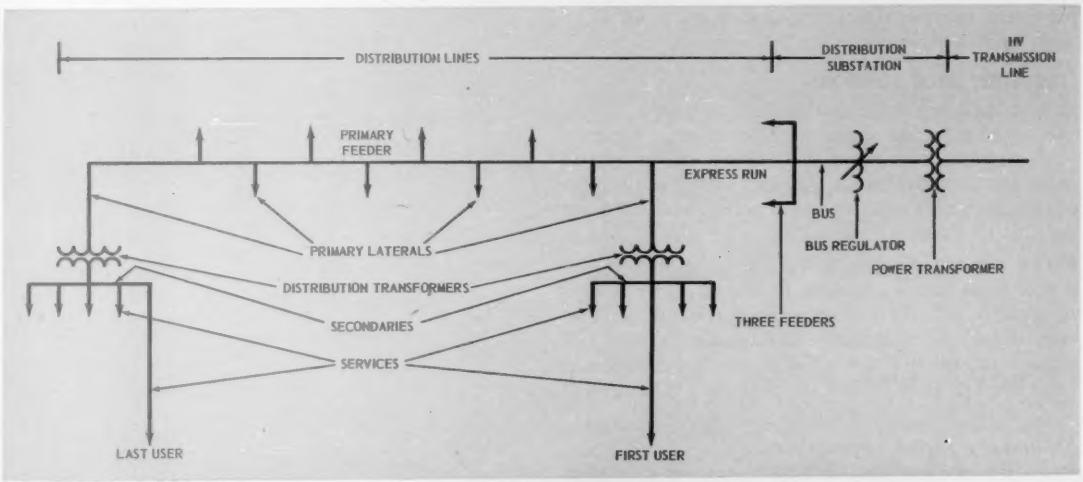
Primary lateral

The primary lateral is a short primary branch, often single phase, and usually of No. 6 copper equivalent. Since some transformers are connected directly to the main feeder, there is no lateral voltage drop to the transformer, so line *D-F* can be drawn for the user with high voltage. The maximum design voltage drop allowed in laterals is 1½ volts (on a 120-volt base), so line *B-E* can be drawn for the customer with the most voltage drop.

Primary feeder

From Figure 1 it is evident that if one distribution transformer were connected to any one primary main line at the source, the maximum permissible source voltage to deliver satisfactory service to users fed from that transformer would be that of points *D, F* and *G*, or 129 volts. In some cases this voltage restriction would be very costly, since it would limit the effectiveness of substation bus regulation to all feeders from that source to only 5½ volts. Therefore, at least a 2-volt drop must be designed into the primary feeder, and the lines *F-H* and *E-H* may be drawn requiring a 131-volt source.

The practical solution to high voltage near the source is to backfeed the load. Where the load near the source is single phase, it may be best to tap the main feeder a mile or more away from the source and backfeed. A No. 6 copper equivalent conductor may be strung back toward the source on the fourth pin position of the crossarm carrying the main feeder. Where the source is located in a well-built-up urban area and there are several main feeders leaving the source, it may be desirable to provide an inde-



SYSTEM DIAGRAM helps to visualize the voltage profile from the user to the source. **(FIGURE 1)**

Light-Load Voltage Drops (TABLE II)

	Closest User	Farthest User
Service	0.5	0.5
Secondary	0	1.0
Distribution Transformers	0.5	1.5
Primary Lateral	0	0.5
Primary Feeder	0.5	2.0
Total	1.5	5.5

pendently regulated special feeder to supply the load.

It is almost always practical to backfeed some of the load close to a source, so that at least a 2-volt drop in the main feeder is included in the total drop to all customers at heavy load periods. In some cases it is practical to obtain more than 2 volts drop by the use of backfeeds, as it increases the allowable voltage drop on all other feeders from the substation.

The light-load condition solved

Table II shows the light-load voltage drops obtained when the full-load condition indicated by the solid lines *A-H* and *C-H* is set up.

The voltage shown as point *J* on the chart is 123.5 volts or 3.5 volts above the optimum. The 3.5 volt value is the average of the total drop. The voltage drops shown in the table are plotted back from *J*, for the closest customer giving point *K*, and for the farthest customer giving point *L*.

As a result, the average user receives 120 volts at both heavy and light loads, the farthest user receives 114 volts at heavy load and 118 volts at light load, while the closest user receives 126 volts at heavy load and 122 volts at light load. The maximum variation to any one customer is only 4 volts, or half of that normally permissible for satisfactory service.

Properly designed backfeeds can improve conditions by 2 out of 5.5 volts. In terms of bus regulation, this improvement increases the effectiveness of source bus regulators by 36 percent.

Frequently used solutions

In studying low voltage conditions, it is helpful to construct voltage profiles similar to those shown in Figure 1. Voltage drops in excess of those shown can be spotted easily, and corrective means analyzed. There are a number of commonly used solutions to low voltage conditions and each has its merits.

Fixed boost

A fixed boost, such as a distribution transformer or an autotransformer, provides a constant increase in voltage; however, it has the disadvantage of increasing a light-load voltage. In spite of this a fixed boost has considerable merit when properly applied, but generally a variable boost at about the same cost is preferable.

Secondary shunt capacitors

Secondary capacitors are much more than just fixed boost devices, although that is one of their functions. They reduce losses and loading on equipment between their location and the source. The most practical time to install secondary capacitors in the large blocks is at the time when new transformer installations are being made. The fixed boost function of secondary capacitors may be undesirable when located close to a source. If a high voltage complaint is received about the voltage on a transformer near the source when the transformer is on its full primary winding, the secondary capacitors should be removed or possibly switched with thermal switches set for about 80 F.

Tapped distribution transformer

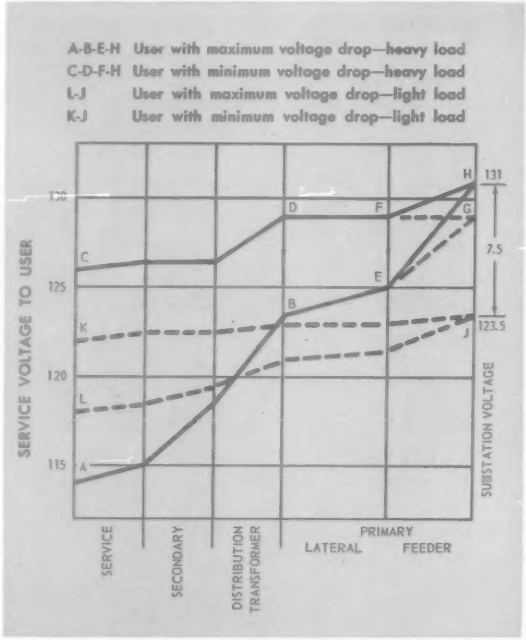
Taps are undesirable in transformer sizes 50 kva and smaller. Not only do they add about 5 percent to the cost of producing the transformer, but they often do more harm than good. Low voltage complaints from users at the ends of long secondaries often cause taps to be reset. This procedure may in turn bring complaints of high voltages from users near the transformer. The proper solution is to rearrange the secondary, thus eliminating further complaints.

Variable boost

There are two types of variable boosts: a constant boost, which is switched in or out of the circuit, such as switched capacitors; and variable boost, such as step-regulators, which usually have thirty-two ⅝ percent steps. Both types may be controlled by time clock, voltage, or occasionally by other means, such as a combination of time and voltage, power, current, and so forth.

Bus regulators

Bus regulators, shown in Figure 3, are normally of 10 percent plus and minus range in thirty-two ⅝ percent steps. This range handles (1) transmission voltage variations, (2) varying voltage drop through the substation trans-



GRAPHICAL ANALYSIS of allowable voltage drops is based on range of satisfactory voltages delivered to the user. **(FIGURE 2)**

former caused by variable load, and (3) compensation for at least some of the voltage drop in the distribution system. Regulators are automatically controlled by two devices working together — a contact-making voltmeter, which senses voltage variations on the line side of the regulator, and a line-drop compensator. When load variations occur the regulator acts to maintain constant voltage at the desired point on the distribution circuit.

In cases where large power transformers supply a considerable number of primary feeders with widely varying load characteristics, the line-drop compensator does not always give the optimum voltage levels. A clock-driven compensator was developed to replace or supplement the line-drop compensator and keep the voltage-regulating schedule on a predetermined pattern, most befitting a typical residential feeder. This modified compensation appears desirable in a great many cases.

Feeder regulators

On long distribution feeders the voltage regulation from heavy load to light load is often more than the station bus regulator can care for. Even if the regulator had sufficient range, the voltage regulation in the primary circuit between the electrically closest user and the farthest user would be more than tolerable. In such cases it is desirable to locate one or two pole-mounted regulators at suitable points on the feeder. Proper location of such regulators is very important.

Recent developments in the single-phase pole regulators, having variable current and regulating capacity, make it possible to obtain regulation within the feeders at a cost savings of as much as 50 percent of those involving three-phase regulators. Single-phase pole-mounted regulators require no land or enclosures; in addition, individual phase regulation is provided.

Switched shunt capacitors

Two types of switched capacitors are used on some systems. One type is switched automatically by time, voltage, or other control means, and inherently requires an oil circuit breaker in addition to the control. This scheme is relatively costly but often desirable. The second type is switched seasonally with manually opened fused switches. Seasonal switching of primary capacitors is often a desirable and inexpensive means of providing part of the necessary voltage control. Secondary capacitors may be switched as suitable and economical automatic switching equipment becomes available. The size of each secondary capacitor is too small to justify the effort and cost of manual seasonal switching.

Series capacitors

Series capacitors are used for correction of voltage fluctuations caused by large, rapidly varying loads, such as large welding machines used in manufacturing. Series capacitors are not normally used on distribution systems.

Regulation is system problem

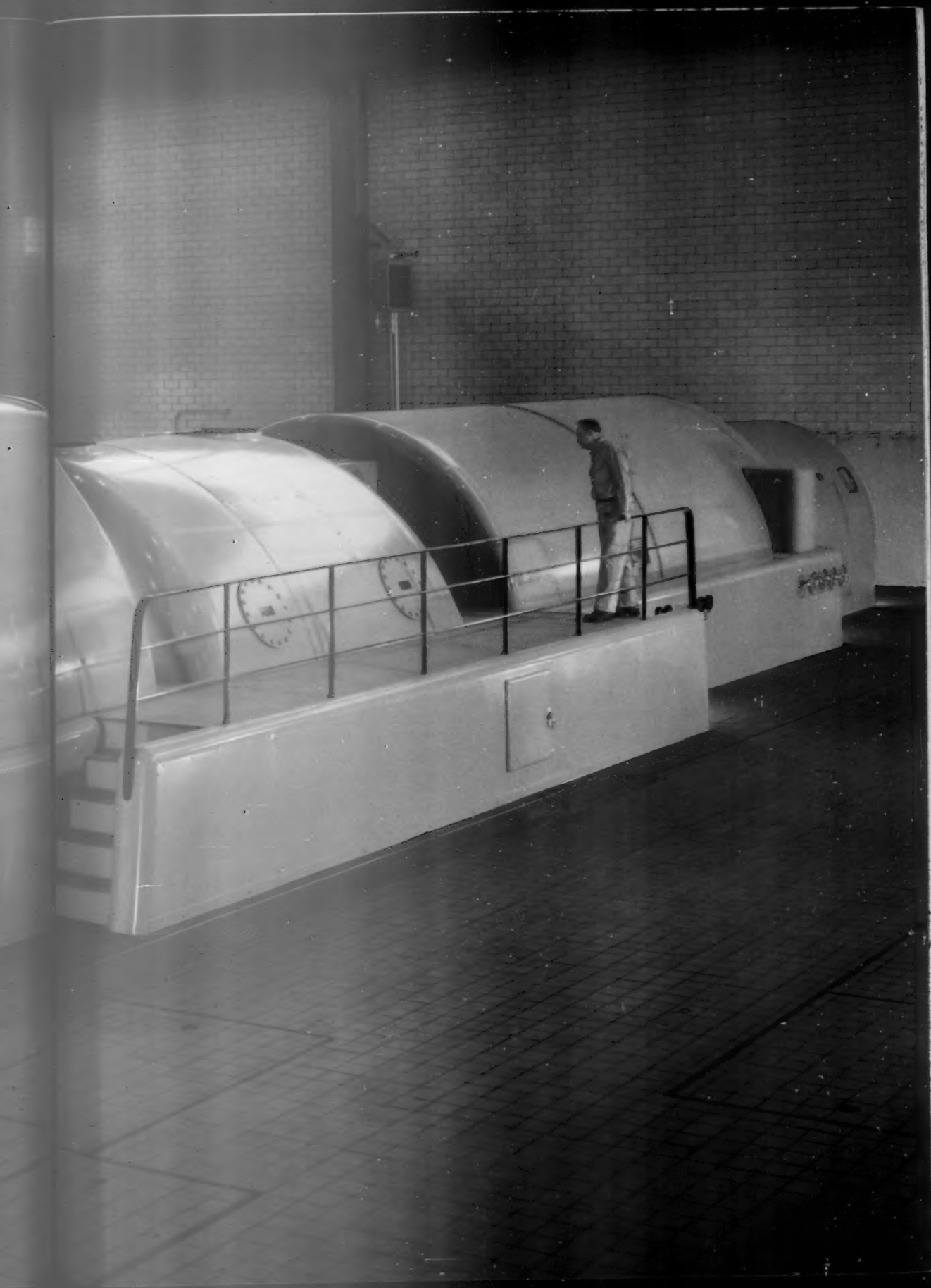
As systems grow, more use will be made of regulators and switched capacitors. Used properly together the two systems of voltage control complement each other. On many circuits having highly seasonal load characteristics it is possible to manually switch the shunt capacitors and have the line regulators maintain satisfactory voltage levels. This method will eliminate costly automatic capacitor switching equipment that would otherwise be required for voltage control.

The growing complexity of distribution system arrangements has given rise to a series of problems in delivering satisfactory voltage to the user. Solving these problems piecemeal as they arise is generally uneconomical. Only by studying an entire distribution system can a lasting solution to the individual voltage problems be obtained. By starting with the user's voltage needs and working back toward the power source, the necessary regulating means can be provided to the user's voltage problems until load changes force another study of the system.

VOLTAGE TO FEEDERS is regulated by bus regulators like these three-phase, 750-kva, 5/8 percent step units on a southwestern system. **(FIG. 3)**

TWO BIG TRENDS in 3600-rpm steam turbine generator units make this new machine — the largest in Minnesota — outstanding. Improved accessibility is dramatized by the side-crossunder tandem turbine design. Pattern for largest ratings of tomorrow is demonstrated in supercharged generator cooling. *A-C Staff Photo by M. Durante*

ALLIS-CHALMERS



Oriented Steel and TODAY'S Turbine Generators

by **G. W. STAATS**
Motor and Generator Dept.
Allis-Chalmers Mfg. Co.

TYPICAL of generators equipped with grain oriented stator core laminations are these 75-mw steam-turbine generators. **(FIGURE 1)**

Generator stator cores of laminated steel reduce machine heating and losses.

GRAIN ORIENTED STEELS, developed especially for low core loss and high permeability, have been used in transformers for a number of years to improve electrical characteristics and to permit easier installation through space, weight, and material reductions. More recently, oriented steel has been used in the stators of a number of large turbine generators like those shown in Figure 1. Appreciable benefits, including reduced core losses and reduced field current for a given generator load, have been achieved.

The desirable properties of grain oriented iron-silicon alloys are obtained through cold reducing at the mill.* This produces an orderly rearrangement of most of the crystal lattices, or elementary patterns of atoms, in such a way that the axes of easiest magnetization are nearly parallel to the direction of rolling. The result is high permeability in the direction of rolling and low core loss in electrical machinery employing this steel.

In a typical transformer, the core is designed to give the useful flux a path that follows, as nearly as possible, one direction along the core laminations. With this construction, full advantage may be taken of the desirable properties of oriented steel.

In a typical large generator stator lamination, the direction of rolling is that given by the arrow in Figure 2. The useful flux in the teeth will be at a considerable angle to the rolling direction, although this angle will change from tooth to tooth. The flux in the ring will, in general, be at only a small variable angle to the rolling direction.

Electrical properties improved

Because of the marked directional properties of oriented steel, and its low core loss and high permeability at high flux densities, it is classified on the basis of the core loss at 15,000 gausses (96,750 lines per square inch) as measured by standard Epstein test. The directional properties of oriented steel at high flux densities are clearly shown by Figures 3 and 4. Figure 3 gives the core loss at 60 cycles for flux at various angles to the rolling direction for stress-annealed 29-gage (0.014 inch) oriented steel. Figure 4 shows the exciting rms volt-amperes per pound for flux at various angles to the rolling direction for the same material.

The interlamination resistance of stator cores is also of particular interest in large turbine generators — because as machine size increases, the difference in potential between the ends of the stator core also increases and the voltage between each pair of laminations must also increase. Adequate insulation between laminations at pressures encountered in stator cores is therefore of paramount importance. A typical curve of interlamination resistance versus pressure is shown in Figure 5.

When grain oriented steel is used for generator stators, the orientation of the ring portion of the stator laminations is more favorable than that of the teeth. At first glance it would appear that, since flux density is greatest

* See "Controlling Processing Lines for Transformer Steel," by E. F. Boening and John Kastelac, in Fourth Quarter, 1955 Allis-Chalmers *Electrical Review*.

in the teeth, orientation should more properly favor the teeth. The converse is true because, even though ring density is somewhat less than tooth density, the total weight of the rings is considerably greater than that of the teeth in the deep cores of turbine generator stators. The most favorable arrangement is to let the ring have the preferred orientation.

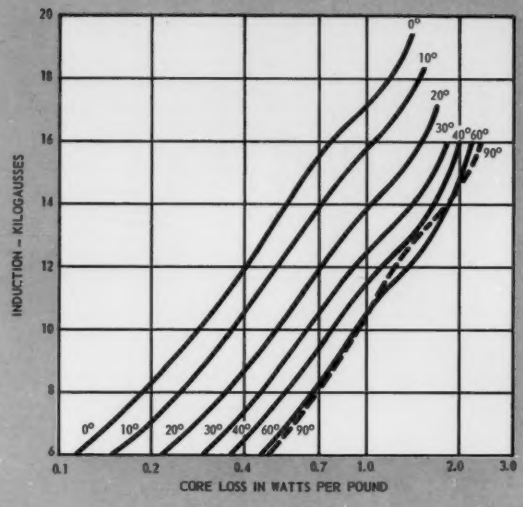
Mechanical properties

Some average physical and mechanical properties of grain oriented steel at room temperature are given in Figure 6. One of the more interesting of these is the variation of the modulus of elasticity depending upon the angle to the rolling direction. This variation, while it may be significant for certain applications, is not a limitation on generator core mechanical design, since the angle between both circumferential and radial directions and the direction of rolling change from point to point in a given lamination, and also because the laminations are staggered as a core is assembled.

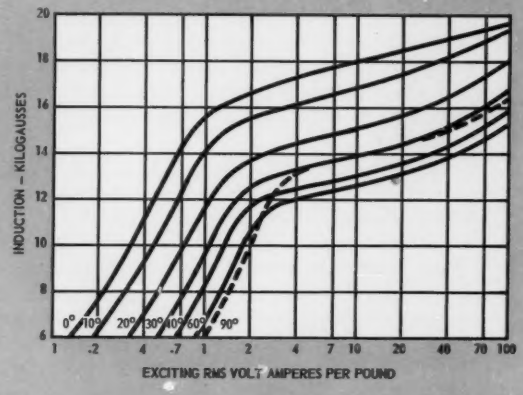
In order to take full advantage of the superior magnetic properties of grain oriented steel, laminations that have been punched or sheared from fully processed material should be annealed at about 1475 F for about one hour (a stress-relief anneal), as the material is more strain sensitive than other electrical steels having essentially non-directional magnetic properties. Non-oxidizing, non-carburizing atmospheres are recommended.

Proved in use

Oriented steel has been used in the stators of a number of large turbine generators in recent years. Operating experience with these machines has been completely favorable. Tangible evidence of the benefits due to the use of oriented steel is given by the curves of Figures 7 and 8. These curves have been drawn from the tests of two 93,750-kva generators located in the same power station. The two machines are identical except that one has an oriented steel stator core and the other has not.

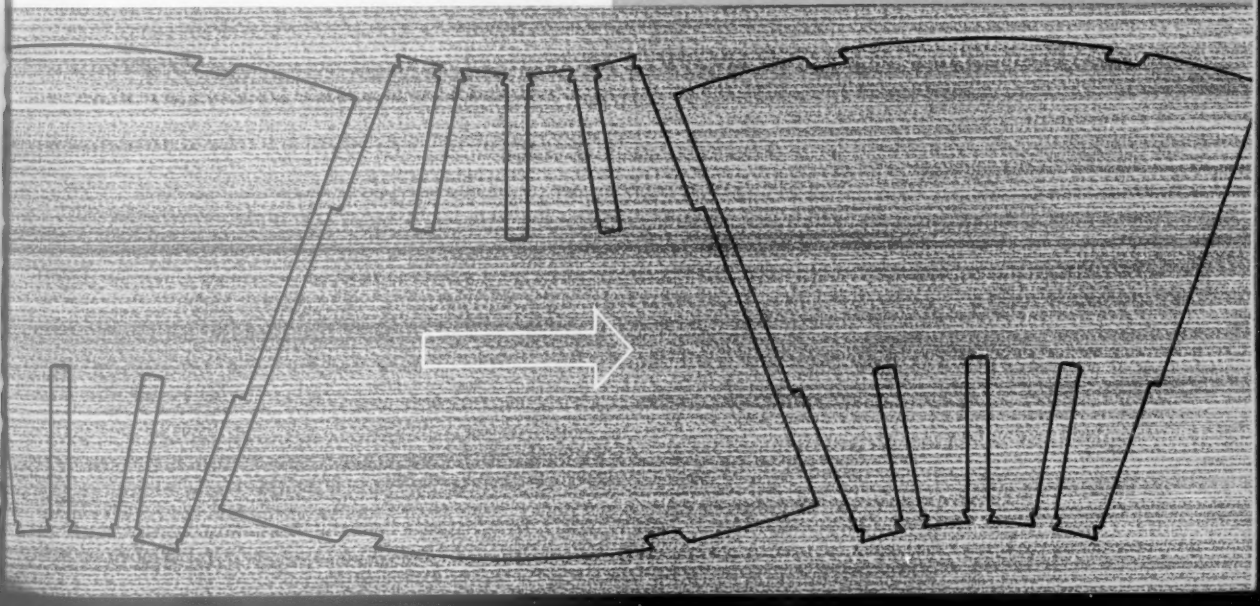


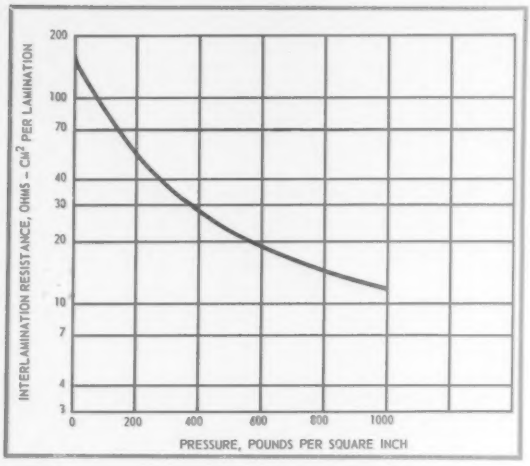
CORE LOSS is substantially less at angles under 30 degrees to the direction of rolling than at greater angles. **(FIG. 3)**



EXCITATION requirements are also substantially lower at small angles to the direction of rolling. **(FIGURE 4)**

STATOR CORE laminations are punched from grain oriented steel sheets in a manner similar to that indicated below. **(FIGURE 2)**





REDUCED interlamination resistance at increased pressure between laminations increases insulation requirements as the potential between the ends of stator cores increases. **(FIGURE 5)**

The two machines mentioned afford an interesting comparison from a noise and vibration standpoint, situated as they are in the same room. Neither machine noise nor vibration has been increased perceptibly by the use of oriented steel.

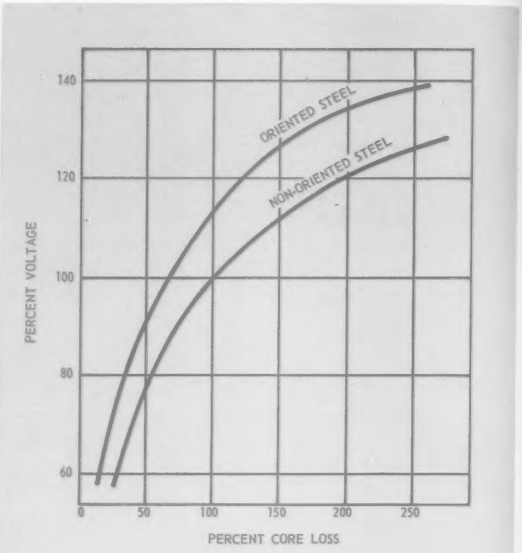
Figure 7 indicates that the use of oriented steel has decreased the core loss 36 percent at rated voltage. Since core loss is a fixed loss, efficiency is improved at all loads, and stator heating is also less at all loads. The curves of Figure 8 show the effect of the increased permeability of oriented steel on the no-load saturation curve. These curves indicate that less field current will be required for a given load on a machine having an oriented steel stator core. This results in still higher efficiency and decreased rotor heating.

Use of oriented steel for large turbine generator stator cores offers attractive advantages in decreased machine losses and heating.

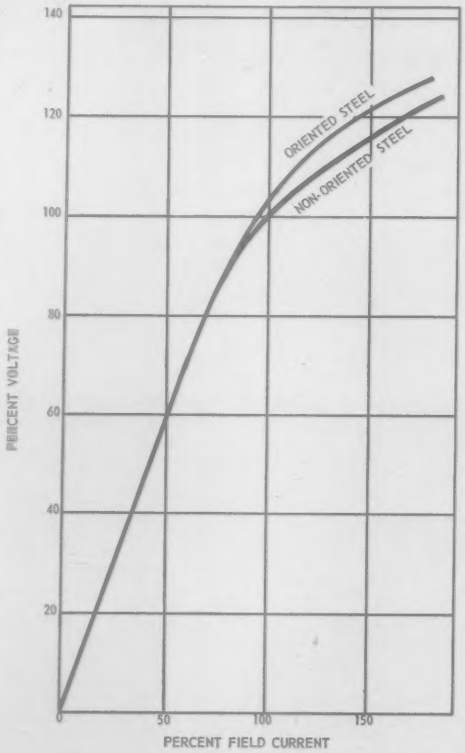
Ultimate tensile strength, psi — in rolling direction.	60,000
Yield strength, psi — in rolling direction.....	48,000
Percent elongation in 2 inches — in rolling direction	17
Rockwell superficial hardness (45T scale).....	52
Equivalent Rockwell B-scale hardness.....	79
Modulus of elasticity, psi* — in rolling direction..	19,000,000
at 20 degrees to rolling direction..	24,400,000
at 45 degrees to rolling direction..	31,400,000
at 55 degrees to rolling direction..	32,000,000
at right angles to rolling direction..	27,700,000
Density — grams per cc.....	7.65
Volume resistivity — microhm-centimeters	48
Volume resistivity — ohms per mil-foot.....	288
Ductility — Ericksen draw in mm.....	5.0

* These values may vary as much as 5 percent plus or minus.

FIGURE 6



COMPARATIVE CURVES for two machines, identical except for stator core steel, indicate substantial reduction in core loss for oriented steel stator core. **(FIGURE 7)**



USE OF ORIENTED STEEL, these curves indicate, will reduce field current requirements. **(FIGURE 8)**

1,300,000-Kva Load Tap Changer

by **W. C. SEALEY**
Chief Engineer
and
S. L. FOSTER
Transformer Department
Allis-Chalmers Mfg. Co.

Load tap changers are keeping ahead of the rapidly increasing kva ratings of today's largest power transformers.

RECENTLY IMPROVED, load tap changers are now available for transformers rated 1,300,000 kva for 20 percent range in 32 steps. When originally developed over 20 years ago, these tap changers were suitable for 400,000 kva, which was considered sufficient for any size transformer in the foreseeable future at that time. Now, however, with transformer banks rated 600,000 kva, and with even larger banks being contemplated, the 400,000-kva unit will no longer have sufficient capacity to take care of the top-rated transformer banks of the future.

The new load tap changer has essentially the same mechanism as the previous designs. Externally, the new units look like the lower rated unit shown in Figure 1. The mechanisms consist of three principal parts: a dial switch mounted on the side of the tank and driven by an intermittent gear, a cam-operated circuit breaker located below the dial switch compartment, and a motor-driven mechanism which operates the circuit breaker and dial switch. A motor-driven tank hoist permits easy inspection of the circuit breaker.

The tap-changing scheme of Figure 2 is universally used in the United States for heavy-duty load tap changers. There are other tap-changing schemes available, many of which have been used principally for lighter duty. For light duty mechanisms the circuit breakers are omitted and the arc is broken either on the dial switch contacts or with contactors in place of the breakers. However, for heavy-duty construction an arc-breaking means adapted from oil circuit breakers was found necessary even though the arcing duty is only a small fraction of the duty required of breakers for system fault interruption.

TABLE I
OIL CARBONIZATION

Number of Operations	Parts per Million of Carbon in the Oil	
	Quick-Break Device	*Ruptor* Device
500	100	20
1000	220	30
1500	480	40
2000	850	50
2500	920	60
3000		70
4000		90
5000		110
6000		130

LOAD TAP CHANGERS capable of handling transformer loads up to 400,000 kva have been in operation for many years. **(FIGURE 1)**

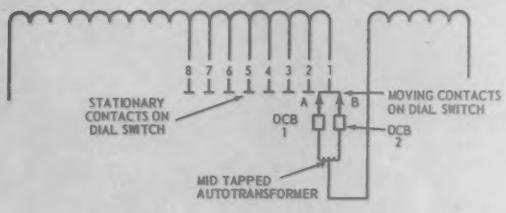
Parallel winding schemes are no longer used for heavy-duty load tap changers because of the increased duty which they impose on the arcing contacts.

Mid-tapped autotransformer preferred

In some countries, other than the United States, a resistance is used instead of a mid-tapped autotransformer for limiting the current when taps are bridged. This arrangement has the advantage of decreasing the arcing duty because of the higher power factor of the current to be interrupted. It has, however, two serious disadvantages. First, only one-half the number of voltage steps are available for the same number of taps; and secondly, it is impracticable to make a resistor capable of carrying full-load current continuously if a mechanism should stay in a transition position.

The load tap changer of Figure 2 can carry full-load current continuously, not only in its operating position, but also in the transition position, if for some reason the mechanism should remain in that position.

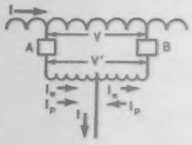
Figure 3 shows the voltage and current relations which exist in the process of load tap changing. Regardless of the power factor of the load, the voltage across the contacts

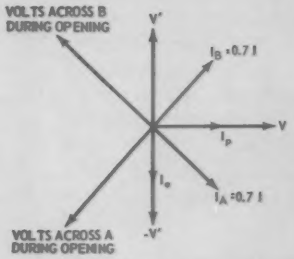


SEQUENCE OF OPERATION

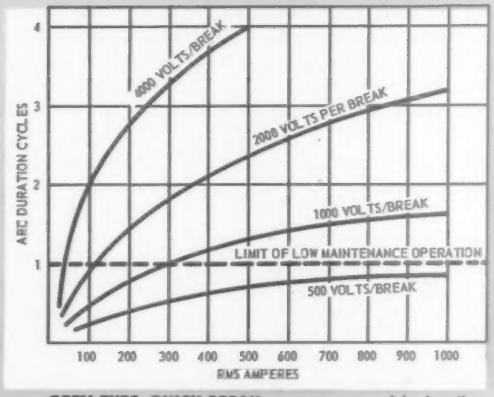
Position No.	Connections			
	A to Tap	B to Tap	CB No. 1	CB No. 2
1	1	1	Closed	Closed
Transition	1	1	Closed	Open
	1	2	Closed	Open
2	1	2	Closed	Closed
Transition	1	2	Open	Closed
	2	2	Open	Closed
3	2	2	Closed	Closed

MID-TAPPED AUTOTRANSFORMER can carry full-load current continuously so unit can remain between tap positions. **(FIGURE 2)**





VOLTAGE AND CURRENT relations at opening are not normally influenced by power factor. **(FIGURE 3)**



OPEN-TYPE QUICK-BREAK contacts can safely handle 1000 amperes at 600 volts with low maintenance. **(FIG. 4)**

is nearly 90 degrees out of phase with the current. Under these conditions, maximum voltage is available across the contacts to cause the recovery of the arc when the current passes zero.

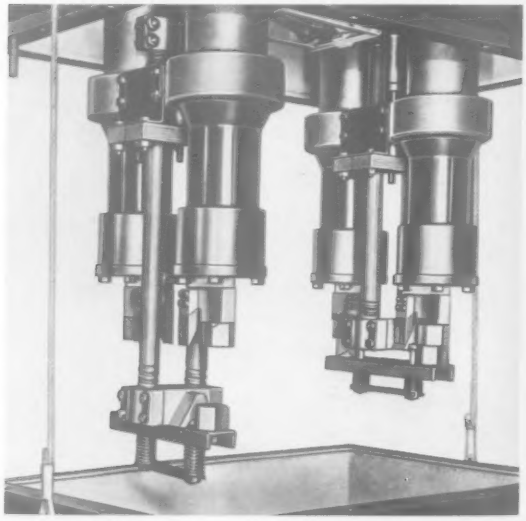
When the power factor is other than unity, one contact will be subjected to a more severe condition of current interruption than the other. In most systems where large load tap changers are used, the power factor does not approach zero but is usually above 80 percent, with the average power factor 90 percent or above. Hence, most of the operations of the load tap changer are at 90 percent power factor or above.

Figure 4 shows the typical interrupting capacity of open-type quick-break contacts such as used in the 400,000-kva rated units. The interrupting capacity of a quick-break contact is not constant with voltage. It appears that about 4000 volts per break is the maximum that is practical for these contacts even at very low currents. The maximum for a single break at 1000 amperes is about 600 volts. By using double break, such as exists in a conventional circuit breaker, this can be raised to 1200 volts per circuit. The curves show a maximum capacity for a winding using open-type quick-break load tap changers of about 400,000 kva per bank with ⅝ percent half-cycling steps. The open-type contacts are shown in Figure 5.

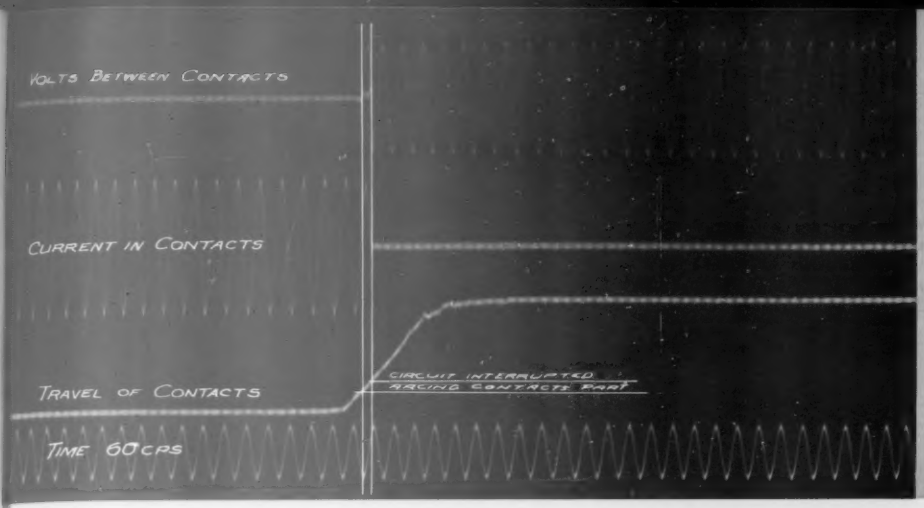
To extend the capacity of a mechanism to regulate above 400,000 kva, a higher interrupting capacity circuit interrupter than open-type quick-break contacts is needed. To gain added interrupter capacity for higher rated load tap changers a new current interrupting device is used. The *Ruptor* arcing principle, which was developed for heavy transmission system circuit breakers, is used with the circuit interrupting contacts of the new higher rated tap changer. This arrangement is shown in Figure 6. Typical test results with this device are shown in Figure 7.

Oil life is factor in design

For long contact and oil life the arc should be interrupted as quickly as possible, but only as phase current naturally



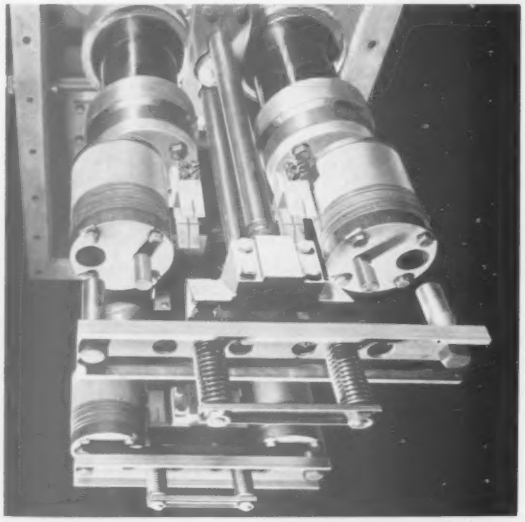
OPEN CONTACTS are used for transformers rated 400,000 kva per bank and having ⅝ percent half-cycling steps. **(FIGURE 5)**



NO RESTRIKE of arc current after interruption at first current zero is important, but oil deterioration increases if the contacts part too rapidly. **(FIGURE 7)**

passes through zero. If the circuit is interrupted at any other point, it produces an undesirable transient voltage across the transformer insulation. The oscillogram shows that the individual phase current is interrupted at the first zero of current after the contacts part. Contacts should part sufficiently in a half cycle so that no restrike of the arc will occur, but not faster than this speed. Beyond this speed the arc will be drawn out, resulting in increased oil deterioration. The deterioration of the oil is proportional to the watt-seconds of energy in the arc that are dissipated in decomposition of the oil.

When an arc is formed in oil, it decomposes the oil immediately around it into hydrogen, carbon and hydrocarbons. An ionized hydrogen bubble which conducts the arc current forms around the arc. To extinguish the arc, it is necessary to cool the hydrogen below its ionization temperature or to extend the contact separation until the voltage gradient is insufficient for conduction. For lower voltages it is possible to extinguish the arc simply by extending the distance rapidly between the contacts, so that the contacts are far enough apart at the end of a half cycle that the hydrogen will not conduct under the potential available. As the voltage gets higher, however, it is not possible to move the contacts far enough in a half cycle to keep the voltage gradient below the ionizing potential at the end of a half cycle.



HIGHER INTERRUPTING CAPACITY was gained with *Ruptor* principle, used in power transmission breakers. **(FIGURE 6)**

The new device agitates the oil in the vicinity of the arc and tends to break up the hydrogen bubble. Thus, when the current reaches zero the hydrogen bubble is broken into a series of small bubbles. The gas in these small bubbles cools rapidly to a temperature below which the gas cannot ionize. In addition, oil barriers between the bubbles prevent the reformation of an arc. The device also tends to reduce the arcing time by forcing the arc to move continuously across the arcing contact. In so doing, the arc spot is continuously forced onto cool metal. The arc spot becomes cooler as the current approaches zero. Since the position of the spot moves continuously, the heat stored in the metal during the peak current will not affect deionization of the arc as the current wave is passing through zero. Both of these factors tend to increase contact life and reduce oil deterioration.

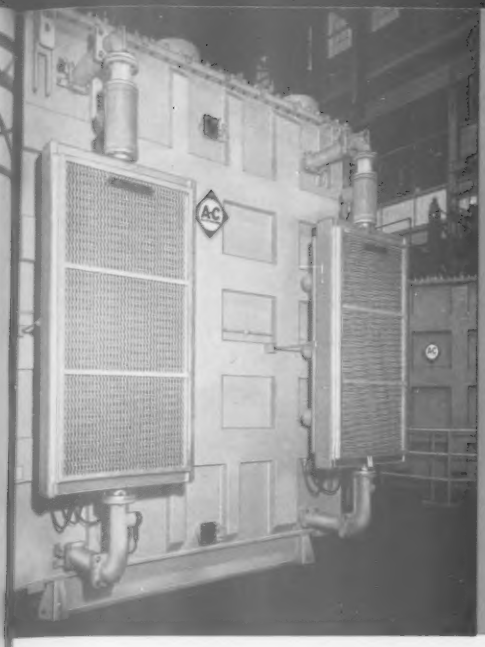
Tests prove contact life

The *Ruptor* breaker, shown in Figure 6, has been life tested at a capacity which would be equivalent to more than a million kva in bank capacity. The amount of carbon produced in the oil by quick-break open contacts and with contacts having the new device is shown in Table I. This test was made with the same load on each assembly and considerably above the limit of low maintenance, as shown in Figure 4.

Very little contact burning was noted at the end of the test. This field test was made on a transformer bank with 1¼ percent steps, which is equivalent to double the effective service on a tap changer switch using ⅝ percent steps. If an auxiliary winding is used, this transformer bank, which is one of the largest now in service, could be built four times its present size using the new load tap changer.

The new breaker has shown that it will operate satisfactorily on transformers with a bank capacity in excess of one million kva and has been tested under simulated operating conditions for a period equivalent to several years of life at this capacity. The unit is now in regular operation on several large banks of transformers and its service record has shown that little maintenance is required.

MORE TRANSFORMER is packed into less space in latest designs. Integral core and tank bracing and modern coolers have contributed most to recent size and weight reductions in new higher ratings. The five 112-kw *Electro-Cooler* units on this 125,000-kva, 330-kv autotransformer are mounted nine feet above ground as a precaution against possible high water in this Midwest power station. Each cooler unit has a 2¾-hp pump motor and nine ⅛-hp fan motors. Coolers are divided into two groups for automatic thermal control.



CONTROLLING Power Transformer Coolers

SPACE SAVING results from forced-air, forced-oil cooling. **(FIGURE 1)**

***ELECTRO-COOLER* FANS** are accessible. **(FIG. 2)**

by **JOHN A. EBERT**
Transformer Dept.
Allis-Chalmers Mfg. Co.

Thermal characteristics of forced-cooled transformers call for careful coordination of cooler control protective schemes.

THE CONFIDENCE OF TRANSMISSION ENGINEERS in the infallibility of present-day power transformers is reflected in the purchases of higher and higher kva ratings. To design these modern higher rated units in practical physical sizes for shipment and erection, forced-oil cooling with space-saving heat exchanger systems is becoming more common.

The systems are designed with enough heat exchanger capacity to dissipate transformer losses. Several sizes of the new cooler units are available, the largest having a heat-dissipating capacity of 150 kilowatts at a 30 C oil rise, and requiring a 2¾-hp pump motor and twelve ⅙-hp fan motors. The cooling systems are usually arranged in groups, with each group consisting of one or more cooler units operated by the same automatic contactor. Typical *Electro-Coolers* are shown in Figures 1 and 2. The hot oil from the top of the transformer tank is forced through the heat exchangers, cooled, and returned to the bottom of the tank. Each cooling unit is provided with a shutoff valve at both the upper and lower bolting flanges so that the cooler may be removed without draining the transformer tank.

Forced cooling is continuous

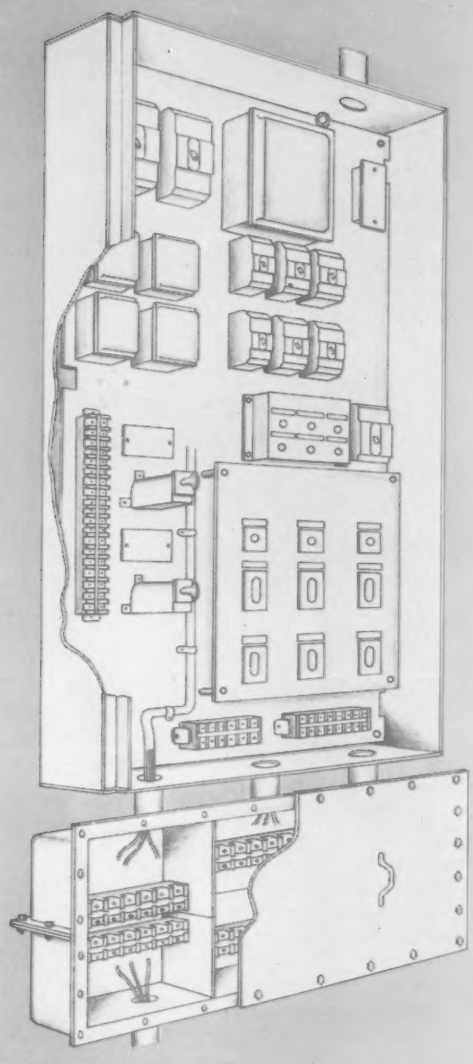
Thermal characteristics of forced-oil-cooled transformers are such that, while maintaining full load, inoperation of the cooling equipment results in a very rapid rise in temperature. There is practically no thermal head to circulate the oil, so that the loss of a pump reduces the heat-dissipating capacity of a heat exchanger unit to nearly zero. If a forced-oil-cooled transformer is carrying full load in an ambient temperature of 40 C while its cooling equipment suddenly becomes inoperative, the transformer will not even carry excitation losses for more than a few hours before excessive temperatures are reached. To protect the transformer, oil circulation and cooling must continue whenever the transformer is energized, regardless of what load the transformer is carrying. Therefore, a safe and efficient control scheme for the pump and fan motors is vital.

A sketch of the type of control equipment normally provided on a forced-oil-cooled power transformer is shown in Figure 3. The control components are located in a large weatherproof control cabinet, mounted on the transformer tank at a level for convenient operation and maintenance. Circuit breakers, contactors, starters and all the other necessary devices are mounted in this cabinet. Leads from the devices on the transformer are brought in conduit to the cabinet and into a split terminal box for connection to outside circuits and alarm systems.

Motor connections are convenient

The leads from fan and pump motors are in Neoprene-jacketed cable, as shown in Figure 2. With the arrangement shown, an individual *Electro-Cooler,* a pump or a fan may be removed from a cooler without the necessity of rewiring conduit or shutting down the transformer.

Pump motors are three phase, totally enclosed, squirrel cage with integrally mounted pumps. Since the complete motor and pump unit is oil-immersed, there are no lubrication or stuffing box problems. Leads are brought out



PUMP AND FAN MOTORS are protected electrically by low voltage manual breakers. Control is provided by contactors, relays and manual switches operating in conjunction with automatic temperature control relays and protective devices. **(FIGURE 3)**

through oiltight bushings. The single-phase capacitor fan motors are weatherproof and have built-in overload devices.

To protect and control the motors adequately, the control scheme must fulfill the following four basic requirements:

1. Provide manual or automatic starting of the coolers. Where automatic starting is necessary, the coolers must be operated by a combination oil and winding temperature device.

2. Give an alarm if any vital cooling component fails and provide switching to an emergency source when motor supply voltage fails.

3. Provide electrical isolation of cooling units to facilitate replacement or repairs of individual units.

4. Disconnect failing motors quickly without disturbing operation of other motors on the cooler system.

The schematic diagram shown in Figure 4 is a basic circuit which fills all four requirements. This arrangement provides a maximum in protection and convenience.

Control functions overlap

The functions of the components of the control scheme overlap in many respects and in some cases operate to satisfy more than one of the four requirements.

A main magnetic-type circuit breaker for each power source is provided to disconnect the entire circuit and to provide overall short-circuit protection, as shown in Figure 4. Circuit breakers supplied for individual coolers are also magnetic breakers and serve the double function of manually disconnecting each cooler unit and at the same time furnishing short-circuit protection. The pump motor manual starting switch provides thermal overload protection as well as manual control. Each fan motor is also provided with a built-in thermal overload relay.

An automatic contactor is provided for each *Electro-Cooler* group. These contactors can be operated by the thermal relay or by an auxiliary contact on the system's generator or main circuit breaker. Since it is customary to use the cooling units only when needed, the first group of coolers is started by the auxiliary contact when the transformer is energized. Subsequent cooler groups are started automatically by action of the thermal relay. A switch is provided to select the sequence of starting groups. Where excitation or small loads are being carried for long periods, only the initial starting group would be operating.

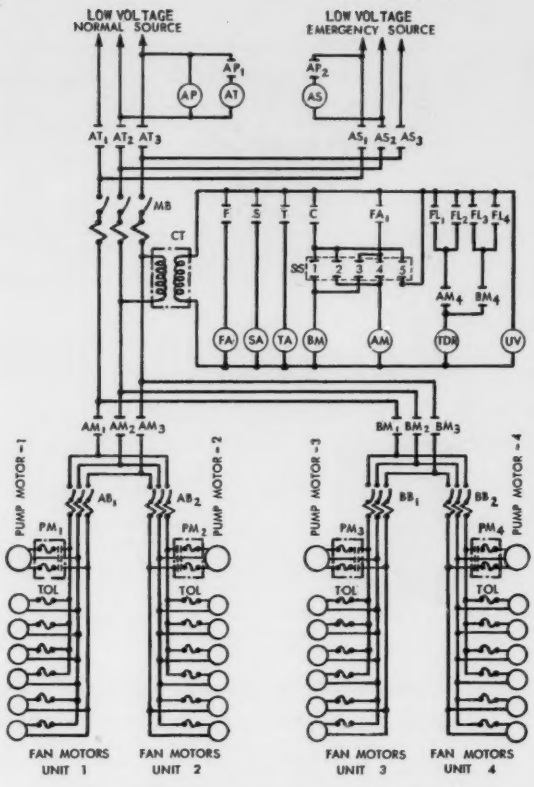
The thermal relay is a bimetal thermal element which is heated by a combination of oil temperature and current proportional to load current. As the bimetal heats and twists, contact is made by three switches—each at a progressively higher temperature. The first contact is used to energize the automatic contactor and start the cooling units. The second closes an alarm circuit indicating excessive temperatures. The third contact may be used to trip the main circuit breaker when the maximum safe operating temperature is exceeded.

Cooling failure is indicated

An oil flow indicator is installed in the bottom elbow of each cooling unit. The contact on the indicator pointer closes an alarm circuit to indicate no oil flow. An auxiliary contact prevents a false alarm when the cooler contactor is not energized. A time-delay relay prevents a momentary false alarm when the cooler is first started and oil flow has not reached the required velocity to move the float of the oil flow indicator. In addition to the closing of the oil flow alarm contact, a failure of cooling equipment will also be indicated by a thermal relay which provides a warning when the transformer is approaching excessive operating temperatures.

NOMENCLATURE

AB1, AB2	CIRCUIT BREAKERS FOR *ELECTRO-COOLER* UNITS OF GROUP *A*
CT	AUXILIARY CONTROL TRANSFORMER
AM	AUTOMATIC STARTER FOR *ELECTRO-COOLERS* OF GROUP *A*
AP	PILOT RELAY ON TRANSFER SWITCH
AS, AT	MAIN CONTACTORS ON TRANSFER SWITCH
BB1, BB2	CIRCUIT BREAKERS FOR *ELECTRO-COOLER* UNITS OF GROUP *B*
BM	AUTOMATIC STARTER FOR *ELECTRO-COOLERS* OF GROUP *B*
F, S, T	CONTACTS ON THERMAL RELAY
FA, SA, TA	AUXILIARY RELAYS OPERATED BY THERMAL RELAY
FL1, FL2, FL3, FL4	FLOWMETER ON *ELECTRO-COOLERS*, CONTACTS CLOSE ON LOW FLOW
MB	MAIN CIRCUIT BREAKER
PM1, PM2, PM3, PM4	MANUAL STARTERS FOR PUMP MOTORS
TDR	TIME-DELAY RELAY ON FLOW ALARM
TOL	THERMAL OVERLOAD ELEMENTS
SS	SELECTOR SWITCH
UV	UNDERVOLTAGE ALARM RELAY

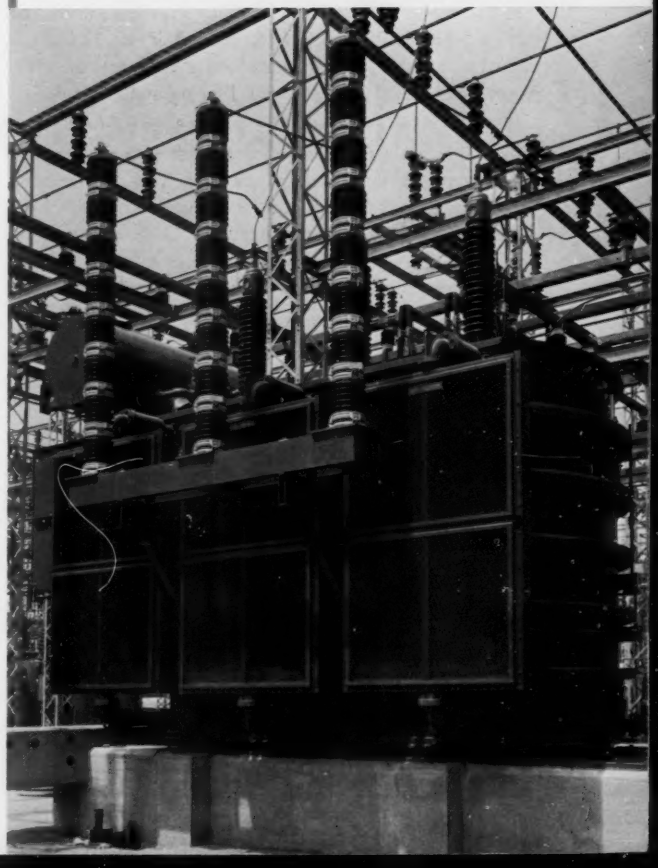


AUTOMATIC TRANSFER of control voltage protects the transformer cooling system against auxiliary power supply failure. **(FIG. 4)**

An automatic transfer switch guards against loss of cooling equipment during voltage failure. The voltage failure protection is obtained with a pilot relay and two automatic, mechanically interlocked contactors. A failure of the normal source will drop out the pilot relay, thereby de-energizing the coil operating the contacts to the normal source, and will energize the coil operating the contacts to the emergency source. The reverse procedure will take place when the normal source is restored.

Since the control cabinet is mounted close to the transformer tank, heat from the tank is transmitted to it by both conduction and radiation. On warm, sunny days, the ambient temperature in this compartment can be well above the normal specified operating ambient of the equipment inside. Therefore, all the magnetic breakers, hand starting switches, contactors and thermal overloads mounted in the cabinet must be derated, so the thermal rating of each device is considered to be 60 percent of the manufacturer's catalog rating.

The completeness of the *Electro-Cooler* control system assures full thermal protection for the transformers. Failure of any cooler motor will not require the removal of the transformer from the system, since the balance of the system will continue to operate. The comprehensive signal system warns the operator of failures. Individual cooler units can be shut down or removed without disturbing the transformer load. The wide application of *Electro-Coolers* on large transformers and even on older units to increase their rating stems from reliable control schemes.



***ELECTRO-COOLER* UNITS** such as used on this 75,000-kva, 115-kv transformer in a southeastern utility save substation space. **(FIGURE 5)**

INTEGRAL DESIGN

Reduces Weight and Size of Large Transformers

by **K. P. WIEDERKEHR**
Engineer-in-Charge
Transformer Design
Allis-Chalmers Mfg. Co.

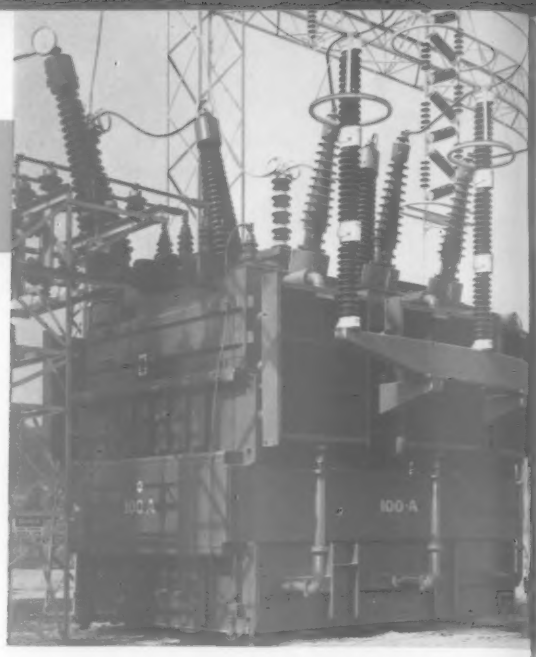
Transformer engineers have been able to design higher rated transformers than ever before without exceeding shipping limits.

TOP POWER TRANSFORMER RATINGS have increased in voltage and kva to a point where designers are reaching practical size and weight limitations for shipping and handling assembled units. To avoid the necessity of field assembly and drying, and to cut material weight and cost, transformer engineers have resorted to integral core and tank bracing and other design simplifications. A unit of this type is shown in Figure 1.

Until recently, transformers were built with the core and coil completely separate from the tank. This arrangement, shown in Figures 2 and 3, requires a core and coil clamping structure and separate tank bracing. Over 20 years ago design engineers tried connecting the transformer core to the tank structure to reduce the material required for tank bracing. The main handicap to this design had been the inaccessibility of core and coils for easy inspection and repair in the field.

As units became more and more reliable, users began switching from single-phase banks of three units with a fourth unit as a spare, to single bank three-phase units without a spare. Single-phase units are now used on exceptionally large banks that cannot be shipped assembled in a three-phase unit. With units rated 300,000 kva and up, where weights are in the neighborhood of 600,000 pounds, users abandoned the idea of field erection. This change in thinking opened new challenges for the design engineer to simplify the construction of large size power transformers.

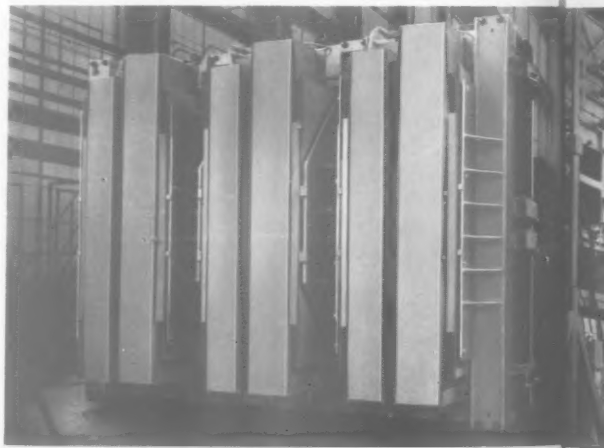
While all transformer cases are braced for pressure and vacuum because they are filled under vacuum with insulating oil, the new design simplifies construction. The combining of coil, core, and tank bracing can be applied to any form of transformer, but to illustrate a method of building a transformer of this type a three-phase shell-form unit is used.



INTEGRAL DESIGN made possible shipment of transformers rated as high and higher than this 125,000-kva, 330-kv, three-phase, class FOA unit installed in a Midwest utility. The unit is one of a number of initial transformers installed on extra-high voltages. **(FIGURE 1)**

Coil and insulation are conventional

The coils and insulation for the new integral design are assembled in the conventional way except that each phase is set up on clamping beams, as shown in Figure 5. Coil clamps are unnecessary, since clamping is part of the tank structure.



ALUMINUM END-FRAMES and other design simplifications made possible separated core and coil constructed transformers in higher ratings and within shipping weight and size limitations. **(FIGURE 2)**

After completion of the coil stacking, clamping beams are added to the top. Each phase is then clamped individually and is then ready for the pre-dryout in a vacuum tank. The pre-dryout requires from 4 to 6 days, depending on size of unit and amount of moisture in the insulation. The dryness is then checked by insulation power-factor readings. When dry, the coil stacks are removed from the vacuum tank and pressed down to the correct size. The three coil stacks are then assembled, maintaining the correct distance between the phases for the iron yokes. The coil stack is then placed in the bottom section of the tank.

The basic tank consists of three parts: the bottom section, the top section, and the center section, as shown on sketch, Figure 4. Each section not only serves as part of the tank but also provides coil and core bracing.

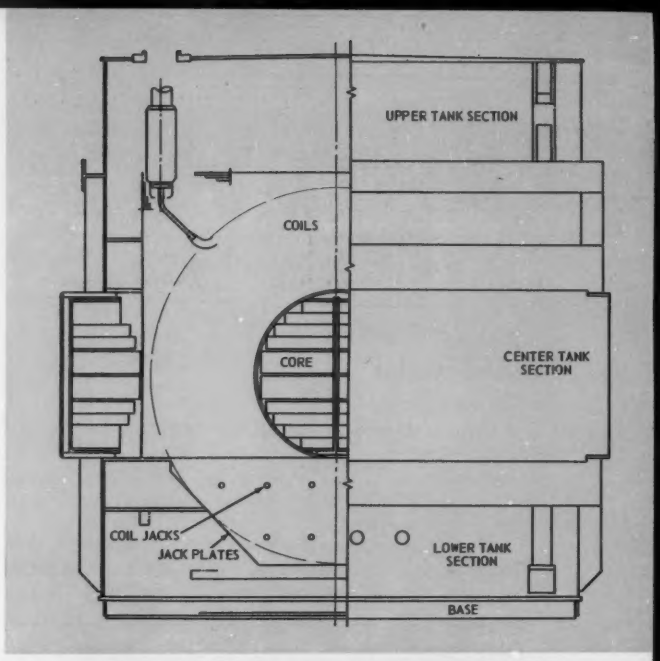
The lower section holds and clamps the part of the coil extending downward past the core. It is a shallow rectangular tank, with heavy cross members dividing the tank into three sections. Aluminum jack plates are fastened to the jack bolts from the cross members on both sides for the inside phases, and to the tank wall on the two outside phases. The inside jack bolts can be adjusted through holes in the tank wall. The flange on the top of the lower section serves as a shelf for the core, while the bottom of the section is reinforced with channels which form the base of the transformer.

The coil stacks are lowered into the bottom section between the coil jacks while the bottom clamping beams are removed one at a time. After the coil stacks are in the correct position, the coil jacks are tightened up and the assembly is then ready for core stacking, as shown in Figure 6. The core iron is then stacked in the usual manner on the shelf of the bottom section, as shown in Figure 8.

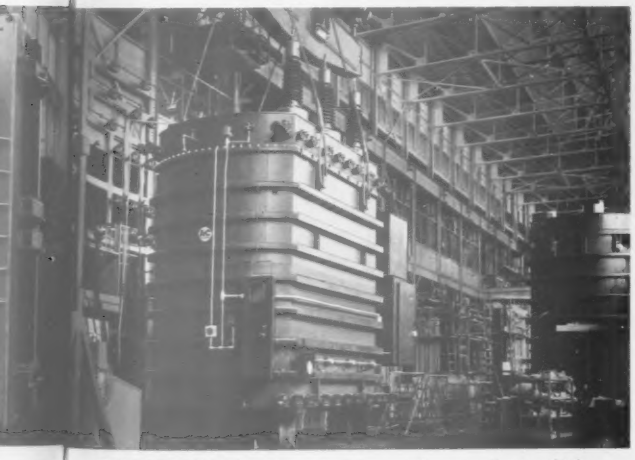
The center section, which holds and clamps the core iron, is made from reinforced steel plates welded to the top and bottom section after the core is stacked. The top section holds and clamps the part of the coil extending upward past the core and provides space for the terminal board and bushings.

The top section is lowered over the upper portion of the coils as temporary clamping beams are removed one by one until the flange of the upper tank section rests on the top of the core iron.

Heavy C-clamps are then used to clamp the core tight between the upper and lower tank section. The four rein-



NEW UNITS in higher ratings are built with the case divided into three sections. While the core and coils cannot be removed from the tank, the upper and center sections of the tank can be lifted off to get at the core and coils should repairs be necessary. **(FIG. 4)**



SEPARATE CASES have been used for transformer ratings as high as the 230,000-kva, 161-kv unit shown. Figure 2 shows the core and coils for this unit. Two cranes were needed to lift it. **(FIG. 3)**

CLAMPING BEAMS are used for coil leads in the integrally designed transformers. These coils were wound and assembled into a 125,000-kva, 330-kv unit for a midwest utility system. **(FIG. 5)**

forced steel plates making up the center section are then welded to the upper and lower tank sections. The complete terminal board has been assembled on the inside of the top section beforehand. Manholes in the cover provide access to the terminal board and permit connections to be made from the coils to the terminal board and to the bushings.

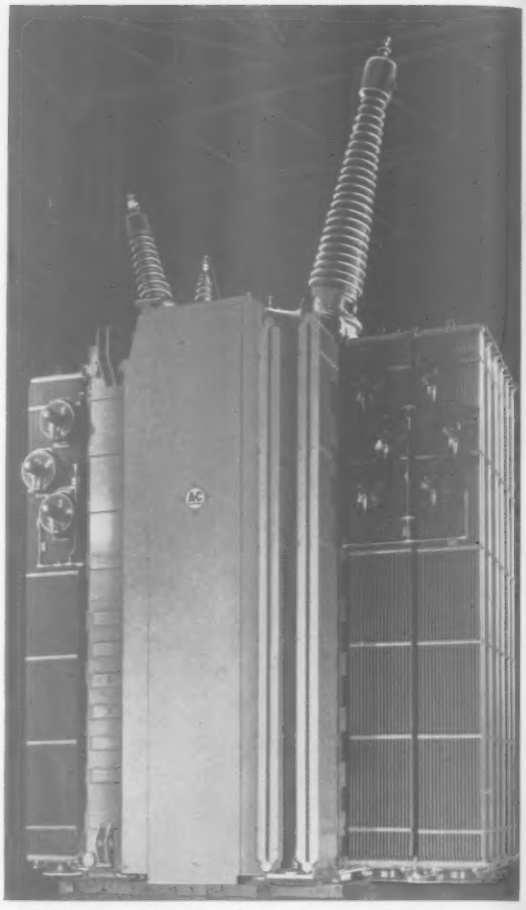
Unit is sealed

The completed assembly is vacuum dried, after which coil jacks are tightened to prevent any movement of the coils during operation. Following this operation the manholes are welded shut and the bushings are installed, thus sealing the unit ready for filling with oil under vacuum.

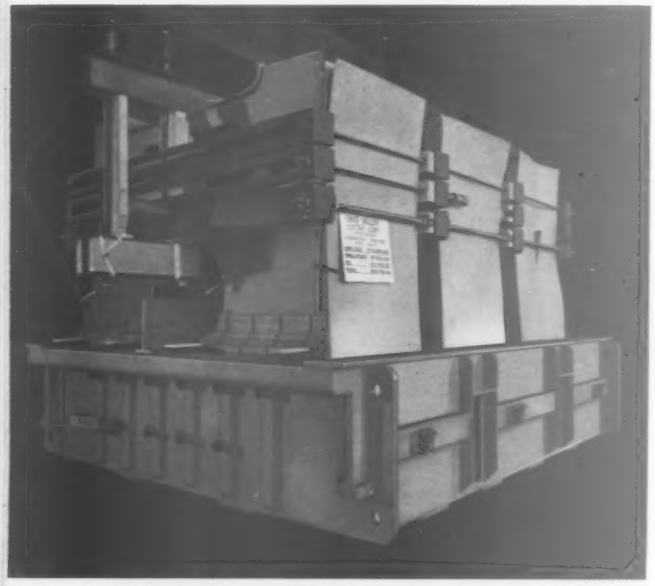
A complete unit is shown in Figure 1. The upper tank section of this unit was constructed in two parts so that a temporary cover could be used to reduce height during shipment. The cover section was welded on in the field.

The same construction can be used for single-phase transformers, as shown in Figure 7. The core on the three-phase unit in Figure 1 is in a horizontal plane, while the single-phase transformer in Figure 7 is in a vertical plane. This construction is very flexible and can be used with but minor modifications to most transformers to cut down shipping dimensions. A 10 to 20 percent weight reduction is obtained by combining coil and core clamping with the case on larger units.

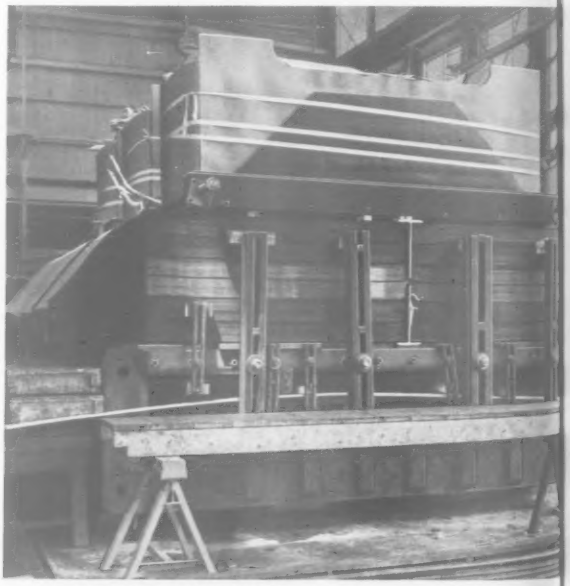
If field repair is required it is not necessary to remove the four side plates. The welds of the side plates to the bottom section can be cut, allowing the top and middle section to be lifted as one piece.



SINGLE-PHASE UNITS like this 200-mva, 345-kv transformer are assembled in the same manner as three-phase units. **(FIGURE 7)**



LOWER TANK SECTION holds the coils, and the core laminations are stacked on shelf of the lower section. **(FIGURE 6)**



REINFORCED STEEL PLATES which form the center section of the case hold and clamp the core laminations. **(FIGURE 8)**

ALLIS-CHALMERS

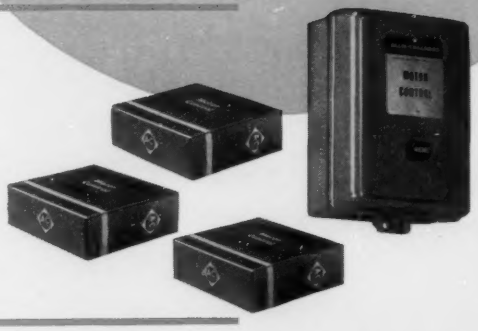
MOTOR CONTROL

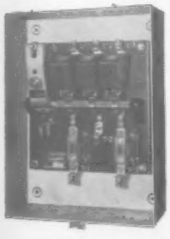
a Complete Line

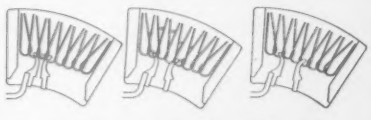
SIZE 0-3 STARTERS

Converta-Kits Permit Easy Modification of Basic Starter

You get MORE . . . more flexibility with Allis-Chalmers control. A screwdriver and the proper *Converta-Kit* are all you need to change a basic Allis-Chalmers size 0-3 starter into the exact unit demanded by your production. *Converta-Kits* are available for push-button, selector switch and electrical interlock modifications. Starter replacement parts—contacts, magnetic coils and overload relays—are also available in packaged kits.







1. Arc across contacts as they start to open.
2. Strong blowout action forces arc to center.
3. Contacts fully open — arc extinguished.

NEW LINE OF SIZE 4-5-6 STARTERS

Quick Quenching Extends Contact and Chute Life

Heart of these starters is a new contactor which uses a revolutionary principle of arc interruption. In centering the arc, increased blowout action and fast quenching result from a combination of thermal convection and magnetic action. Since the arcing time is sharply curtailed, contact and chute life are greatly extended.

HIGH VOLTAGE STARTERS

Complete "Line-to-Load" Control and Protection

Allis-Chalmers Type H starters are built in a wide range of ratings for squirrel-cage, wound-rotor and synchronous motors . . . for full or reduced voltage — reversing or non-reversing — with plugging, dynamic braking and multi-speed features. Built into the starter is the type and degree of protection dictated by the application.

What is your control problem?

As manufacturers of a diversified line of industrial equipment, Allis-Chalmers has solved thousands of control application problems. This specialized experience is yours when you specify Allis-Chalmers control. See your Allis-Chalmers representative or write Allis-Chalmers, General Products Division, Milwaukee 1, Wisconsin.

A-4988

Converta-Kit is an Allis-Chalmers trademark.

A-C ALLIS-CHALMERS

ALLIS-CHALMERS

Choose Condenser Shape to Simplify Plant Layou

Get high operating efficiency of Multi-Steam-Path Condensers in Round, Oval or Rectangular shape

This adaptability of Allis-Chalmers condenser design adds flexibility to plant layout without sacrifice of efficiency. This means freedom for you in planning future power stations.

Multi-steam-path design makes all tubes completely effective by directing the steam to even the remote sections of the condenser, thereby producing a high vacuum.

Steam, penetrating all parts of the condenser, keeps condensate temperature high and drives off dissolved oxygen.

This combination of high vacuum, high condensate temperature and good deaeration means high operating efficiency.

Talk over the special requirements you have in mind for future stations with Allis-Chalmers engineers. Call your nearby A-C office, or write Allis-Chalmers, Power Equipment Division, Milwaukee 1, Wis.

ALLIS-CHALMERS

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